

Improvement of Digital Image Motion Compensation by Fuzzy Inference

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Abstract— In this paper, a fuzzy inference digital image stabilization method is proposed to adaptively determine better motion compensation method through the selection of two different motion compensation methods. The experimental results show the good performance. It solves the problem of lag and overshoot of motion trajectory.

Keywords- fuzzy inference; DIS; motion compensation;

I. INTRODUCTION

Digital image stabilization (DIS) system is generally composed of two processing units. One is the motion estimation unit and the other is the motion compensation unit. The purpose of motion estimation unit is to estimation the reliable camera global movement. The motion compensation unit generates the compensation motion vector to obtain a smoother image sequence [1]-[5].

In the motion compensation of DIS, accumulated motion vector estimation and frame position smoothing (FPS) are the two popular approaches [6]. The accumulated motion vector estimation needs to compromise stabilization and intentional panning (constant motion) preservation since the panning condition causes a steady-state lag in the motion trajectory. The FPS accomplished the smooth reconstruction of an actual long-term camera motion by filtering out jitter components based on the concept of designing the filter with appropriated cut-off frequency. The disadvantage of FPS is that it does not guarantee the availability of the determined compensating motion vector when the specified-bound is restricted to preserve the effective image area in the DIS applications [8].

Fig. 1 shows the motion compensation schematics. The window of frame(t-1) is the previous compensated image. The compensating motion vector v is generated by the DIS according to the global motion vector between two consecutive images. The window of frame(t) is the picking window according to the compensating motion vector v to minimize the shaking effect. Compensating motion vector should be less than window shifting allowance for preservation of the whole image presented in the frame. How to generate motion compensation vector to achieve the optimal stabilization of shaking images within a specified compensation range (window shifting allowance) is a state of the art.

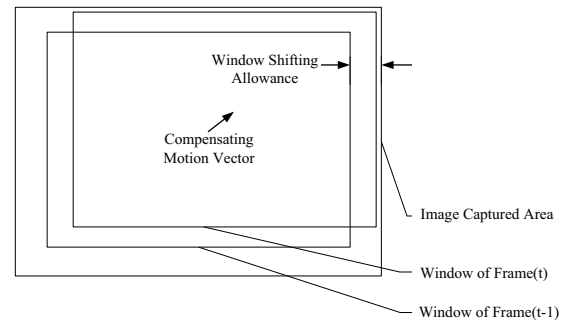


Fig. 1. Motion compensation schematics.

J. K. Paik proposed the accumulated motion vector method in 1992. The computation procedure is given by:[1]

$$CMV(t) = k(CMV(t-1)) + (\alpha GMV(t) + (1-\alpha)GMV(t-1)), \quad (1)$$

where t represents the frame number, $0 < k < 1$ and $0 \leq \alpha \leq 1$. The constant k is used for smooth panning. The constant α is used to filter out the unexpected noise effect. The increase in k causes the decrease in unwanted shaking effect but the increase in the value of CMV leads more allowance to compensate. It means that, in the definite allowance, it may not fully stabilize the image sequence by the CMV , especially in a high panning condition.

S. C. Hsu etc. proposed the CMV computation procedure to attack the drawback of tremendous lag during constant panning in 2005. This is presented by: [7]

$$CMV(t) = k \bullet CMV(t-1) + GMV(t) - \beta \bullet CMV_I(t-1) \\ CMV_I(t) = CMV_I(t-1) + CMV(t) \quad , \quad (2)$$

$$CMV(t) = \frac{1}{2} (|CMV(t) + I| - |CMV(t) - I|)$$

where $\begin{bmatrix} 0 \\ 0 \end{bmatrix} \leq k, \beta \leq \begin{bmatrix} 1 \\ 1 \end{bmatrix}$, $\bullet$ denotes array multiplication.

The objective of motion compensation is to achieve the optimal stabilization of shaking images within a specified compensation range (window shifting allowance). Eq. 1 can get a good result in a general case. But in the constant motion case, the undesired shaking effect cannot be eliminated by this method. The equation proposed in Eq. 2 can overcome this

drawback. The inner feedback-loop integrator was combined with a clipper function to reduce the steady-state lag for steady motion, as well as to keep the CMV operating in the appropriate range. Due to the characteristics of the integral, the overshoot will occur in certain back and forth low frequency image panning. Fig. 2 shows overshoot in low frequency back and forth image panning. The motion trajectory has obvious overshoot. This overshoot will reduce the effect of stabilization.

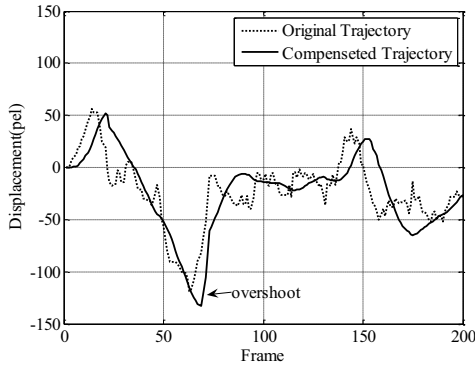


Fig. 2. Overshoot in low frequency back and forth image panning.

In this paper, two methods of motion compensation will combine through fuzzy inference to decide the optimal compensation method. In the next section, the architecture of fuzzy inference applied to DIS will be proposed. Section III shows the experimental results and section IV makes a discussion.

II. METHOD

A. Architecture of fuzzy inference

The typical architecture of a fuzzy logic decision system is comprised of four principal components: a fuzzifier, a fuzzy rule base, an inference engine, and a defuzzifier. The fuzzifier transforming crisp measured data into suitable linguistic values. The fuzzy rule base stores the empirical knowledge of the operation. The inference engine is the kernel of the decision system, and it has the capability of simulation human decision making by performing approximate reasoning to achieve a desired result based on the fuzzy rule base. The defuzzifier yields a nonfuzzy decision to perform the desired action [9][10].

In this paper, the design idea is to keep the merits of each motion compensation method, i.e. reduce compensated motion trajectory lag and overshoot, to improve the DIS in different conditions. Fig. 3. shows the architecture of fuzzy inference applied to digital image stabilization. The system architecture will focus on the motion compensation unit. The motion compensation unit includes two motion compensation methods, fuzzy inference system and motion compensation. Due to the differences of environments, conditions and shaking patterns of the captured images, the different motion compensation methods have individual merits separately. Fig. 4 shows the architecture of the fuzzy inference system. The pre-process block inputs global motion vector (GMV), compensating motion vector #1 (CMV#1, CMV#2) are to transform into

delta of short term smoothness index($\Delta SI(n)$) and delta of deviation(Δd) which are inputs of fuzzy inference. The fuzzy inference determines the weighted value to calculate the compensation vector. And then the block of image compensation uses the compensation vector to stabilize the image sequence.

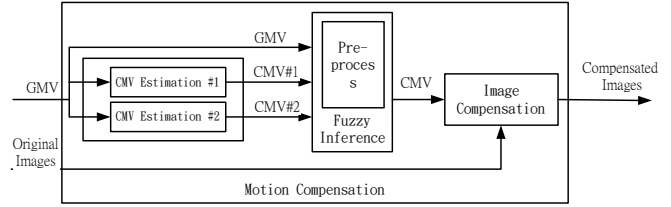


Fig. 3. The architecture of fuzzy inference applied to digital image stabilization

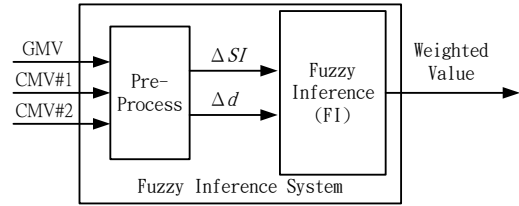


Fig. 4. The architecture of the fuzzy inference system

B. Pre-process

The main function of pre-process is to transform external signals into distinguished signals of fuzzy inference input. The major consideration is the smoothness index. To realize the effect of the compensation method in a short term period, the short term smoothness index $SI(n)$ is defined as

$$SI(n) = \frac{1}{p+1} \sum_{i=n-p}^n \Delta m(i) \quad (3)$$

$$= \frac{1}{p+1} \sum_{i=n-p}^n m \times |GMV(i) - GMV(i-1)|$$

where n is the frame number, p is the short term frame amount. The delta of short term smoothness index($\Delta SI(n)$) can be expressed as

$$\Delta SI(n) = SI \#1(n) - SI \#2(n) \quad (4)$$

where $SI \#1(n)$ and $SI \#2(n)$ are short term smoothness indexes generated by Eq. 1 and 2, respectively.

When $\Delta SI(n) < 0$, the motion trajectory compensated by CMV#1 is smoother than what was compensated by CMV#2 and vice versa. The secondary consideration is the deviation between the original and compensated motion trajectories. The deviation ($d(n)$) is defined as

$$d(n) = |MTraj_o(n) - MTraj_c(n)| \quad (5)$$

where $MTraj_o(n)$ is the original motion trajectory and $MTraj_c(n)$ is the compensated motion trajectory. The motion trajectories are define as

$$MTraj_o(t) = \sum_{i=1}^t GMV(i) \quad (6)$$

$$MTraj_o(t) = \sum_{i=1}^t GMV(i), \quad (7)$$

The large deviation between original and compensated motion trajectories will affect the image stabilization result. Therefore, the delta of deviation (Δd) is defined as a distinguished signal which is expressed as

$$\Delta d(n) = d\#1(n) - d\#2(n) \quad (8)$$

where $d\#1(n)$ and $d\#2(n)$ are deviations of motion trajectory compensated by CMV#1 and CMV#2. When $\Delta d(n) < 0$ means the deviations of motion trajectory compensated by CMV#1 is better than compensated by CMV#2 and vice versa.

C. Membership functions

Fig. 5 shows the Architecture of internal fuzzy inference. It contains a fuzzifier, a fuzzy rule base, an inference engine and a defuzzifier. The function of the fuzzifier is to transform crisp measured data $\Delta SI(n)$ and $\Delta d(n)$ into suitable linguistic values. The membership functions of these two signals are shown in Fig. 6. The linguistic descriptors are: large negative (FN), small negative (SN), zero (Z), small positive (SP), large positive (LP). Fuzzy rule base is characterized by a collection of fuzzy IF-THEN rules in which the preconditions and consequents involve linguistic variables. The collection of fuzzy inference rules characterizes the simple input-output relation of the system. The Eq. 9~19 are the statements of fuzzy rules:

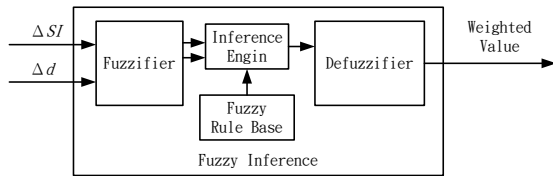


Fig. 5. Architecture of internal fuzzy inference.

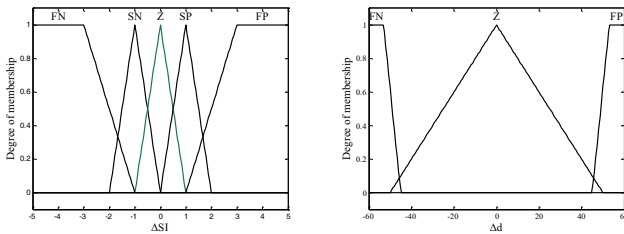


Fig. 6. Membership functions of inputs (a) $\Delta SI(n)$; (b) $\Delta d(n)$.

IF ΔSI is SN and Δd is FN THEN Output is L (9)

IF ΔSI is SN and Δd is Z THEN Output is L (10)

IF ΔSI is SN and Δd is FP THEN Output is M (11)

IF ΔSI is Z and Δd is FN THEN Output is L (12)

IF ΔSI is Z and Δd is Z THEN Output is M (13)

IF ΔSI is Z and Δd is FP THEN Output is S (14)

IF ΔSI is SP and Δd is FN THEN Output is M (15)

IF ΔSI is SP and Δd is Z THEN Output is S (16)

IF ΔSI is SP and Δd is FP THEN Output is S (17)

IF ΔSI is FN THEN Output is L (18)

IF ΔSI is FP THEN Output is S (19)

Mamdani's fuzzy implication method R_c , associated with the min operation, is used in the proposed inference system. The membership function of output signal is shown in Fig. 7. The linguistic descriptors are: large (L), Medium (M), small (S). The output represents the weighted value of motion compensation method#1. Because two methods are included in the system, the final motion compensation vector is calculated by:

$$CMV(n) = k \times CMV(n-1)$$

$$+ y(n) \times (CMV\#1(n) - CMV\#1(n-1)) \quad (20)$$

$$+ (1 - y(n)) \times (CMV\#2(n) - CMV\#2(n-1)),$$

where $y(n)$ is the weighted value, $0 < k < 1$, $CMV\#1(n)$ and $CMV\#2(n)$ are the compensated vectors estimated by method #1 and #2.

Defuzzifier is a mapping from a space of fuzzy set defined over an output universe of discourse into a space of nonfuzzy set. The method of defuzzification used in the fuzzy inference system is the center of area (COA).

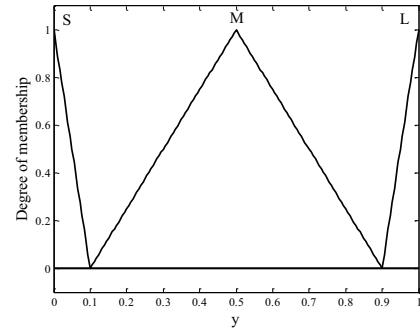


Fig. 7. Membership function of output.

III. EXPERIMENTAL RESULTS

In this section, the performance of proposed method in various conditions is demonstrated. To do this, GMVs estimated by three real video sequences that contain 200 frames are named GMV#1~3. To simplify the problem, one horizontal dimension is discussed and illustrated. The characteristics of GMVs are: GMV#1 contains constant speed movement and small fluctuation, GMV#2 contains constant speed movement and large fluctuation, GMV#3 contains only fluctuation without constant speed movement. The three sets of GMV observe the effects of image stabilization. The image size of the experiment is 640x480 pels. The clipper is bounded within ± 53 pels. Parameters of MC#1 are set $k =$ and

$\alpha =$, MC#2 are set $k = 0.95$ and $\beta = 0.015$, the proposed method is set $k = 0.98$.

Fig. 8. shows the result of proposed method which uses a short term smoothness index to determine the better compensation method. The sequence $n=1\sim 200$ corresponds to GMV#1, $n=201\sim 400$ corresponds to GMV#2, and so on. In the first segment ($n=1\sim 200$), the CMVs processed by MC#1 and MC#2 have almost the same $SI(n)$. Therefore, the fuzzy output is about 0.5. In the segment of $n=250\sim 400$, the $SI(n)$ of MC#1 is higher; then the fuzzy output is close to 0. In other words, MC#2 has a better $SI(n)$ in this segment. In the segment of $n=422\sim 438$, the $SI(n)$ of MC#2 has a spiked shape. Therefore, the fuzzy output approaches 1 and MC#1 is selected to compensate. Obviously, FIDIS is superior to MC#1, MC#2, respectively, for evaluating motion trajectory, the smoothness index or the short term smoothness index.

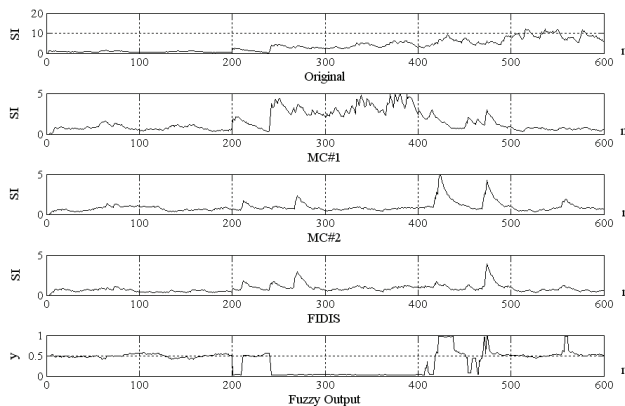


Fig. 8. Proposed method illustrated by short term smoothness $SI(n)$ and fuzzy output.

IV. DISCUSSION

The objective of motion compensation is to achieve the optimal stabilization of shaking images within a specified compensation range. The proposed method combines two motion compensation methods to adaptively determine a better method for motion compensation. It solves the problem of lag and overshoot of motion trajectory. The proposed method

shows effective improvements in different conditions of image sequence through the evaluations of a smoothness index and motion trajectory.

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