Image Sequence Stabilization Using Membership Selective Fuzzy Filtering

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Abstract. Image sequence stabilization aims to remove unwanted fluctuations from an image sequence. This paper proposes a novel stabilization system making use of a fuzzy filter constructed by dynamic system based estimator definition with a fuzzy corrector. The stabilization system selectively switches between a pre-defined set of membership functions so as to improve gross movement tracking and stabilization performance. The stabilization results of the proposed system are compared with results of the Super SteadyShot stabilization system incorporated into SONY® camcorders.

1 Introduction

An important problem in image sequences captured by hand held digital cameras is originated by the fluctuations caused due to unwanted camera motions during video capture. Image stabilization is performed to prevent the affect of these fluctuations. Image stabilization is nowadays commonly used or likely to be used soon in contemporary systems such as hand-held cameras, 3G mobile phones and robot-camera applications.

Motions encountered in image sequences can be classified into two types: global frame motion and local object motion. The global frame motion is of main interest for the image stabilization system as it reflects the movements of the imaging system or framework. The stabilization system typically aims to remove undesired fluctuations encountered in the global frame motion while retaining long-term intentional movements [1]. Hence, it is possible to break up the frame motion into desired frame movements and unwanted fluctuations.

The image stabilization system typically consists of two parts, namely the motion estimation and motion correction systems. The motion estimation system is responsible for obtaining interframe motion parameters. The motion correction system resolves the fluctuation components and accomplishes stabilization. The efficiency of the image stabilization system depends on the accuracy of the motion estimation system, as any error in the motion estimation system directly affects the stabilization system performance [1]. Various techniques for image sequence stabilization have been proposed, such as motion vector integration [2], DFT filtering

A. Yazici and C. Şener (Eds.): ISCIS 2003, LNCS 2869, pp. 497–504, 2003.

based frame position smoothing [1], Kalman filtering based stabilization [3], and Fuzzy adaptive Kalman filtering based stabilization [4]. In the latter case, Fuzzy adaptation of the Kalman filter is utilized to improve stabilization performance, as fuzzy adaptation has proven to outperform classical techniques. This paper proposes image sequence stabilization by directly utilizing a Fuzzy Filter to suppress high frequency components of absolute frame positions obtained by the accumulation of interframe motion vectors.

2 Fuzzy Filtering

Fuzzy logic based systems have been used extensively in image and signal processing applications in recent years. Fuzzy systems provide an effective and smart approach to many nonlinear and uncertain systems. An application of fuzzy logic in image and signal processing for instance is noise filtering. In this paper, fuzzy logic is used in an estimator structure referred to as a fuzzy filter, to stabilize the fluctuations of image frame positions.

2.1 Fuzzy Estimation

In this section, the structure of the estimator used for stabilization is explained. Fuzzy logic has been used as correction function of the estimator in a similar approach to [5].

A standard discrete time-invariant system can be defined by the process and observation equations

$$x_{k+1} = f(x_k) + w_k \tag{1}$$

$$z_k = h(x_k) + v_k \tag{2}$$

where k is the time index, x_k is the state vector, z_k is the measurement vector, v_k is the measurement noise and w_k is the process noise. To find an estimate $\hat{x}_k$ to the discrete time signal, the commonly used estimator architecture known as the recursive predictor-corrector is given by

$$\hat{x}_k = \hat{f}(\hat{x}_{k-1}) + g(z_k, \hat{x}_{k-1}) \tag{3}$$

where $\hat{f}(.)$ shows an estimate of $f(.)$ which maps the state from one time step to the next, and $g(.)$ is the correction function of the system.

The fuzzy estimator structure, which estimates the stabilized frame position by a constant velocity camera model [3], can be constructed as

$$\hat{x}_k^- = \hat{x}_{k-1}^+ + T\hat{v}_{k-1} \tag{4}$$

$$\hat{x}_k^+ = \hat{x}_k^- + g\left(z_k, \hat{x}_k^-\right) \tag{5}$$

where k is the time index, $\hat{x}_k^-$ is the a priori estimate of x at time k, $\hat{x}_k^+$ is the a posteriori estimate of x at time k, T is the update period of the estimator, z_k is the noisy image sequence frame position and $\hat{v}$ is an estimate of the rate of change of frame motion speed, which is typically obtained from

$$\hat{V}_{k-1} = \left(\hat{x}_{k-1}^+ - \hat{x}_{k-2}^+\right)/T \tag{6}$$

The correction function $g(.)$ typically has an uncertain mathematical model as instantaneous fluctuations are unknown. In this paper it is proposed to implement the correction function $g(.)$ by a fuzzy system. As the correction function uses fuzzy logic, the estimator structure is referred to as a fuzzy filter.

2.2 Filter Parameters

The structure used for the fuzzy correction system is displayed in Figure 1. The implemented correction system has two inputs and one output. The input variables are given by

$$I1_k = z_k - \hat{x}_k^- \tag{7}$$

$$I2_k = I1_k - I1_{k-1} \tag{8}$$

where input 1 ($I1$) depends on the difference between the k-th index of unfiltered image sequence frame positions and the a priori estimate $\hat{x}_k^-$. Input 2 ($I2$) is calculated from the difference between current and previous indexes of input 1.

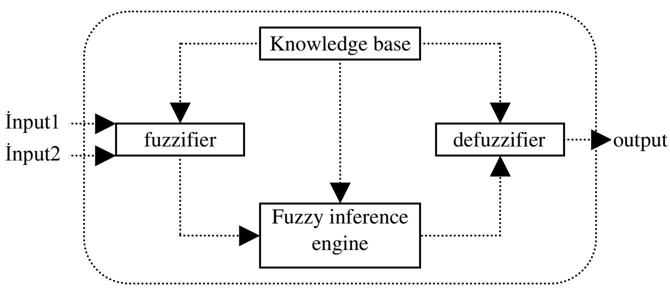


Fig. 1. Fuzzy correction system block diagram.

The shape and parameter selection of membership functions (MF) depends directly on the designer's experience, as there is no inherent way to select membership functions. In the proposed system five Gaussian MFs are used for each input and output, as they are thought to be more appropriate for the desired task. A Gaussian MF is entirely specified by the two parameters $\{c, \sigma\}$, where c represents the MFs mean (centre location) and the standard deviation σ determines the width. A Gaussian membership function can be expressed as

$$y = gaussian(x; c, \sigma) = e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2} \tag{9}$$

In the design of the fuzzy system, membership functions and the rule base play key roles for optimal system performance. In the implemented stabilization system, input and output membership functions are adjusted off-hand to obtain the best results. The utilized membership functions are displayed in Figure 2. The constructed rule base containing 25 rules is shown in Table 1.

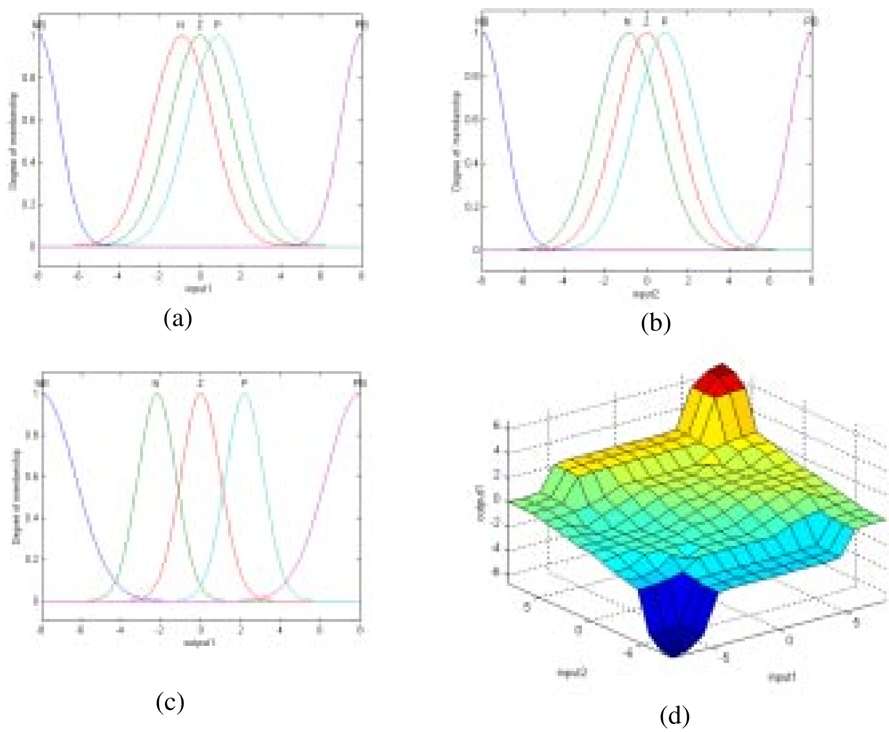


Fig. 2. Membership functions for (a) input 1 (b) input 2 (c) output (d) surface

Table 1. Rule base for the fuzzy filter

		Input2				
		NB	**N**	**Z**	**P**	**PB**
Input1	**NB**	NB	N	N	Z	Z
	N	N	N	Z	Z	P
	Z	N	Z	Z	Z	P
	P	N	Z	Z	P	P
	PB	Z	Z	P	P	PB

*NB = negative big, N = negative, Z = zero, P = positive, PB = positive big

Large fluctuations in the frame position signal can obstruct optimum working conditions for the fuzzy filter. Hence, these fluctuations are preliminary reduced by a mean operation accomplished by the so called preprocess unit. The preprocess unit calculates mean values using present and past two values of the frame position vector, as shown in equation (10).

$$z_{k-1} = \left(a_k + 2a_{k-1} + a_{k-2}\right)/4 \tag{10}$$

Raw frame positions before and after preprocessing are denoted as a_k and z_k respectively.

In order to have the fuzzy filter operate successfully with a limited number of membership functions, every membership function has to be defined to comprise a limited range. However, if the membership function ranges are limited for optimum operation it is sometimes possible for the input values to exceed the total range of the pre-defined fuzzy filter membership functions. This will largely reduce the performance unless precautions are taken. To prevent this problem, it is proposed in this paper to use 7 separate pre-defined output MF sets. The output MF set utilized by the system is selected from between the 7 possible alternatives according to the rate of change of undesired fluctuations.

In order to introduce selective alternation of membership function sets, the positions of the two membership functions directly affecting the operation of the fuzzy filter, namely the negative (N) and positive (P) MFs, are varied. The position of membership function centre locations with respect to each other directly determines the operation of the fuzzy filter. If the distance between membership function centre locations is increased the fuzzy filter will track global frame positions more closely, but the stabilization intensity will decrease. On the contrary, if the distance between membership function centre locations is reduced, the fuzzy filter will not track global movements as closely but the stabilization performance will increase. The intervals used for the membership functions are shown in Figure 3.

3 Simulation Results

Test sequences have been captured by a digital camcorder mounted on a remote controlled model vehicle, navigating on rough terrain. As it was desired to compare stabilization results of the proposed system with Super SteadyShot results available on the SONY® camcorder, two sequences have been captured one with the SteadyShot system active and one with the SteadyShot system disabled. The model vehicle was started at the same position and has been navigating on a similar path (slightly changed due to terrain structure). The absolute frame positions of the sequence captured with SteadyShot disabled are processed with the proposed fuzzy filter based stabilization system. Figure 4 displays the frame positions of the sequence stabilized with the proposed fuzzy-filter based stabilization system and the sequence captured with SteadyShot enabled. Although there is an offset in the long-term displacements resulting from the vehicle taking slightly different routes due to the rough terrain structure, similarities show that the captured sequences are comparable. It is clearly seen in Figure 4 that the proposed fuzzy filtering based stabilization system has less high frequency components and hence provides improved stabilization.

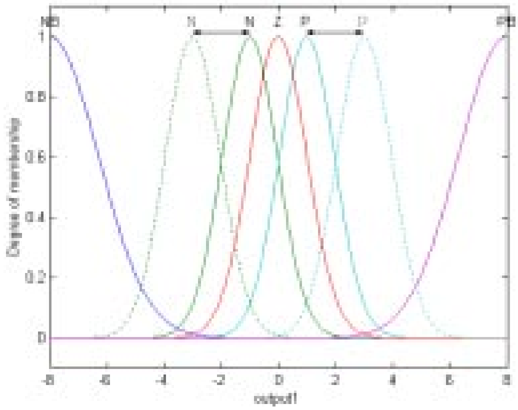


Fig. 3. Changing range between output membership functions centre locations

Figure 5 displays the magnitude spectra of stabilized image sequences using the proposed Fuzzy filter based stabilization system and SONY® Super SteadyShot respectively. It is seen from the magnitude spectra that the proposed fuzzy filter based stabilization system results in lower frequency components, thus achieves a smoother absolute frame displacements and hence provides preferable stabilization performance.

4 Conclusions

A fuzzy filtering based image sequence stabilization system has been proposed in this paper. Absolute image frame displacements are defined by a constant camera velocity model dynamic system and a fuzzy based correction function is utilized. The stabilization system performance is improved by adding selectiveness for output membership functions between a pre-defined set of functions. Stabilization results are compared with the Super SteadyShot system supplied with SONY® camcorders and it is shown that successful stabilization results are achieved.

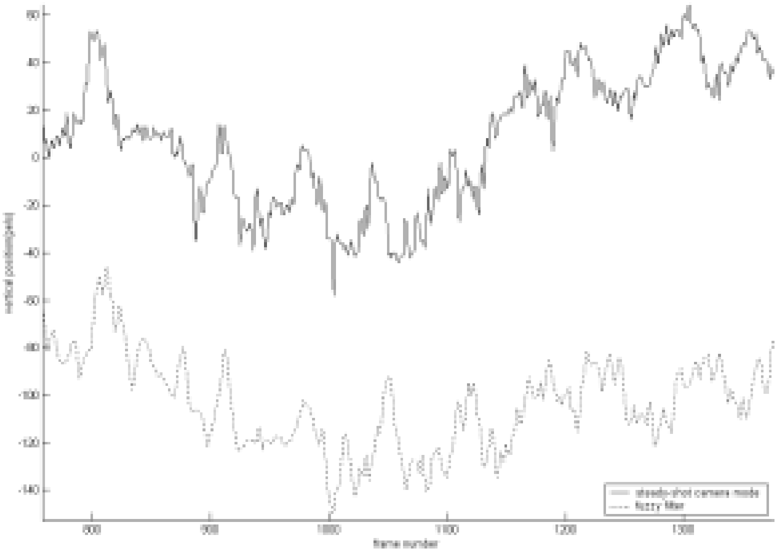
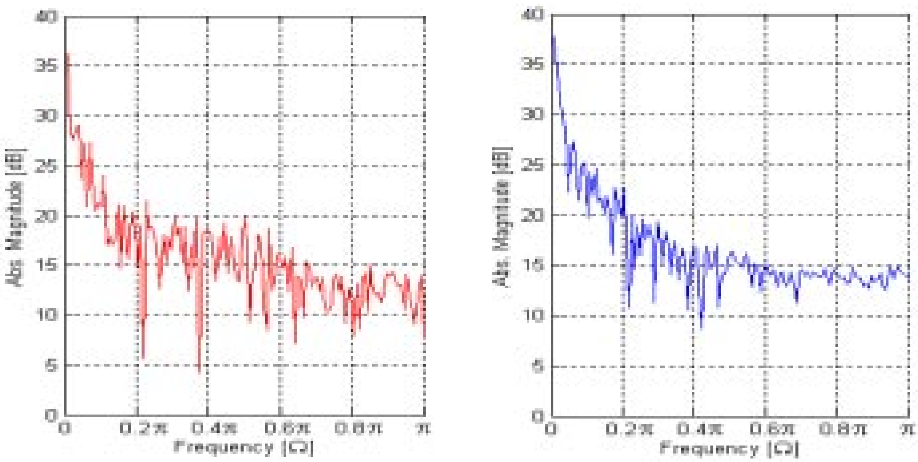


Fig. 4. Output frame position vectors of the steady-shot mode of the digital camera and fuzzy filtered normal mode



(a) (b)

Fig. 5. Magnitude spectra of frame positions (a) SONY® Super SteadyShot (b) Proposed fuzzy filter stabilization.

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