Design of FIR Filter for Water Level Detection

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***Abstract*—**This paper proposes a new design of spatial FIR filter to automatically detect water level from a video signal of various river surroundings. A new approach in this report applies "addition" of frames and a "horizontal" edge detector to distinguish water region and land region. Variance of each line of a filtered video frame is used as a feature value. The water level is recognized as a boundary line between the land region and the water region. Edge detection filter essentially demarcates between two distinctly different regions. However, the conventional filters are not automatically adaptive to detect water level in various lighting conditions of river scenery. An optimized filter is purposed so that the system becomes robust to changes of lighting condition. More reliability of the proposed system with the optimized filter is confirmed by accuracy of water level detection.

***Keywords*—**water level, video, filter, detection.

I. Introduction

RECENTLY, the natural disaster from flood destroys many human lives and their properties. Many areas of the world have to be unfortunate. Especially, the area near to the main river is more possible to incur this peril. How to protect the calamity from flood by detecting water level of the river from video signal is the purpose of environmental surveillance. Various kinds of river surveillance systems have been developed to prevent water disasters [1]. For many areas in Japan, the "telemeter", which is installed by the Japanese government, collects information on water level at several points [2]. However, the observation points are limited to a few principal rivers.

Robust and intelligent river surveillance systems using video signal processing have been proposed to detect water level in the river. Water level detection algorithms have been proposed by Takagi [3],[4]. They are based on detecting bending points of diagonal lines on a measuring board. However, their performance is sensitive to stains on the lines and it is strictly controlled by an administrator to install any obstacle to water flow such as the board in the water.

It is desired to develop a video processing algorithm without setting any board in the water. A Hough transform based algorithm can detect a line which represents water surface [5]. However, it is difficult to discriminate a line which represents the water level from various line-like disturbances.

A simple method based on edge detection is proposed by Tsunashima et al. [6]. It detects a horizontal line as surface of the running water with a “vertical” edge detector. It also employs “subtraction” of frames to make it robust against horizontal line like disturbances on the wall of a channel. However, it is sensitive to moving disturbances such as rain or snow drops due to the subtraction; temporal high pass filtering.

A robust recognition algorithm based on the synchronous frame addition [7],[8] has been proposed so that the effect of moving disturbance such as rain or snow drops is reduced. It was modified from the texture recognition algorithms in [9],[10] applying the wavelet in JP2K in stead of Gabor filter bank. It contributes to reduction of signal processing complexity because a part of compression is shared with recognition. Moreover, we have already proposed a water level detection using functionally layered video coding [11],[12]. Since the wavelet in JP2K is replaced by Haar transform in a sensor node then the system becomes more sample signal processing and low power consumption. Data compression and recognition are installed in a single process. Water level is detected using multi-dimension of feature value which determines by the maximum likelihood (ML) estimation [7]-[12].

In this paper, we propose a design of spatial FIR filter in which it is automatically adaptive to various lighting conditions of river scenery. Water level detection algorithm based on “horizontal” edge detection and frame “addition”. One dimension of feature vector is calculated as variance of each horizontal line. The method determines each line whether it is in the water region or in the land region, rather than detects a line which represents the water surface. The water level is recognized as a horizontal boundary line between the two regions. Optimization of spatial FIR filter is performed so that distance between classes of feature vector is maximized. It is helpful to detect water level in various lighting conditions of river scenery. Reliability of water level detection is comparatively confirmed in aspect of the error of detection.

II. Water Level Detection Algorithm

A. Synchronous Frame Addition (SFA)

The proposed algorithm is based on “horizontal” edge detection and frame “addition”. Reliability of water level detection depends on classification of high frequency component in land region and low frequency component in water region. An example of river scenery is illustrated in Fig. 1(a). Some moving objects such as snow drops and waves of running water evidently appear in a frame of video signal. Fig. 1(b) shows one dimension of frequency amplitude characteristics of land region and water region before frame addition.

To classify the difference between two regions for simply detecting water level, synchronous frame addition is applied

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in Fig. 1(c). Some moving objects become burred and its high frequency components are reduced. On the contrary, non-moving textures such as concrete blocks of the water channel remain their high frequency components. In this example, thirty frames during one second are added. This number is experimentally determined in [8]. Frequency amplitude characteristics between both classes in Fig 1(d) are increasingly distinguished by comparing with Fig. 1(b).

B. Spatial Filtering (Edge Detection)

Spatial filtering is applied so that the difference of the spectrum between the two regions is emphasized and detected. In this paper, we propose a "horizontal" edge operation to detect horizontal lines of water level and compare it with "vertical" edge detection proposed by Tsunashima et al. [7]. An example of filtered signal is illustrated in Fig. 1(e) using three tap band pass filter as edge operator. For this case, variance of each horizontal line is used as feature value illustrated in Fig 1(f). Feature vector is used for classifying distance between classes of water and land region. Spatial filtering is more helpful to expand its distance between classes. Many spatial FIR filters discussed in section III are comparatively utilized, including an optimized spatial FIR filter.

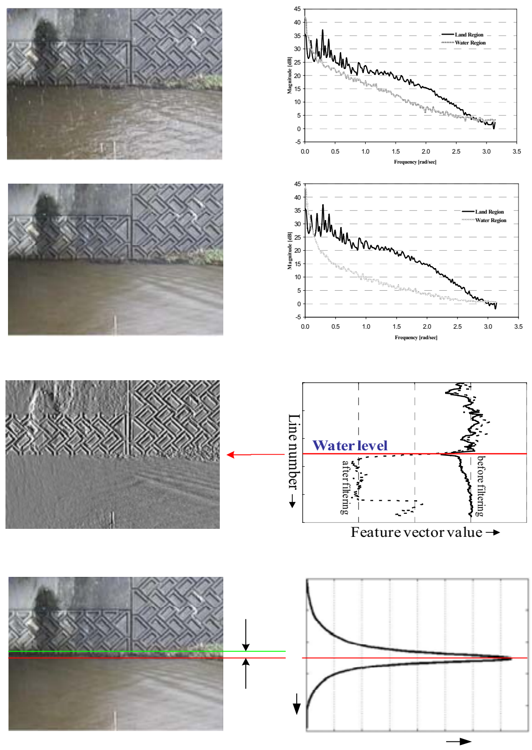


Fig. 1. The proposed water level detection procedure.

C. Water Level Detection

After the frame addition and the horizontal edge detection, feature vector value of each horizontal line in the image is calculated to determine whether it belongs to the water region or the land region. In this report, variance of each horizontal line is used as one dimensional simply calculated feature vector value.

Example of the feature value is indicated in Fig. 1 (f). There is no difference before the frame addition, however, significant difference can be observed after the frame addition. The water level is recognized as the horizontal boundary line between the two regions. Setting a temporary boundary, feature values in the land region "FV_L" and those in the water region "FV_W" is calculated. Similarly, the mean values "m_L" and "m_W" of "FV_L" and "FV_W" is also calculated as well as their variances "s_L" and "s_W". From these values, the ratio defined by

$$\frac{D_{bc}}{V_{wc}} = \frac{P_L P_W (m_L - m_W)^2}{P_L s_L^2 + P_W s_W^2} \tag{1}$$

is calculated to evaluate whether the boundary is proper or not. Appropriate boundary is considered to be the point which clearly separates the two regions (classes): maximize the distance between the classes D_{bc} and minimize the variance within each of the classes V_{wc}. A horizontal line at the maximum ratio of distance between classes D_{bc} and variance within classes V_{wc} in Eq. (1) is determined as the water level. In equation (1), P_L and P_W denote probability of pixels which belong to land (L) class and water (W) class respectively. In this paper, the boundary is detected which maximizes only the distance between the classes D_{bc}.

D. Reliability of Water Level Detection

The method of water level detection is performed by finding feature value of each horizontal line of video signal. Appropriate boundary is considered to be the point which clearly separates the two regions (classes). Reliability of water level detection is comparatively confirmed in aspect of the error of detection in pixel. It is calculated by the difference between a line by visual detection and a line at the maximum of D_{bc}/V_{wc} of feature vector. Furthermore, the distance between classes D_{bc} is inversely proportional to the error of detection in general. Therefore, the comparative error of detection is also useful to select the best filter among some given filters.

III. Spatial FIR Filter (Edge Detector)

1). Transfer Function

Transfer function of a horizontal spatial filter is generally expressed in the z-transform by

$$H(z_1, z_2) = \begin{bmatrix} z_2^{-1} & 1 & z_2 \end{bmatrix} \mathbf{F} \begin{bmatrix} z_1^{-1} & 1 & z_1 \end{bmatrix}^T. \tag{2}$$

For an example, filter coefficient matrix of horizontally spatial FIR filter with three taps is given by

$$\mathrm{F} = \begin{bmatrix} h_{1,1} & h_{0,1} & h_{-1,1} \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ h_{1,-1} & h_{0,-1} & h_{-1,-1} \end{bmatrix}. \tag{3}$$

Vertically spatial FIR filter is simply expressed by applying transpose of the filter coefficient matrix in (3) substituting into (2).

2). Existing Spatial FIR Filters

Several spatial FIR filters [15,16] have been developed by various researchers. It is essentially an operation to detect significant local changes in the intensity level in an image. Examples of existing operators are illustrated in filter coefficient matrix (F) as follows.

The conventional 1D spatial filters used in this report refer to

$$\mathbf{F}_{HP2} = \begin{bmatrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \quad \mathbf{F}_{BP3} = \begin{bmatrix} 0 & 0 & 0 \\ -1 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, \quad \mathbf{F}_{LAP3} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{bmatrix} \tag{4}$$

where

F_{HP2} : horizontal 1D high pass filter,

F_{BP3} : horizontal 1D band pass filter,

and F_{HP3} : horizontal 1D Laplacian filter.

An example of filtered signal in Fig. 1(e) illustrates by applying the "*BP*3" filter horizontally to the image in Fig. 1 (c). For conventional 2D spatial filter, examples of conventional 2D edge detection operator is widely used such as

$$F_{Prewitt} = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}, \tag{5}$$

$$F_{Sobel} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}. \tag{6}$$

These are the "Prewitt" operator and the "Sobel" operator respectively. And also, the diagonal band pass filters "BPF1" with $\mathbf{F}_{DF1}$ and "BPF2" with $\mathbf{F}_{DF2}$:

$$F_{DF1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}, \quad F_{DF2} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix}. \tag{7}$$

The method applies a "horizontal" edge operator to detect horizontal lines of water level. These various types of spatial filter are comparatively applied to emphasize and detect the water level.

3). Optimization of Spatial FIR Filter

Optimization of spatial filter is proposed so that the water level detection system is automatically adaptive to changes of lighting condition of river scenery. The distance between the classes D_{bc} in (1) is used as a criterion for the optimization. For examples, the optimized 1D and 2D horizontal filters with three taps are applied. Both optimized filters are denoted by the filter coefficient matrix:

$$F_{OPT\_1D} = \begin{bmatrix} 0 & 0 & 0 \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ 0 & 0 & 0 \end{bmatrix}, \tag{8}$$

$$F_{OPT\_2D} = \begin{bmatrix} h_{1,1} & h_{0,1} & h_{-1,1} \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ h_{1,-1} & h_{0,-1} & h_{-1,-1} \end{bmatrix}. \tag{9}$$

All filter coefficients of the optimized filter are determined under the condition of maximizing the D_{bc}.. It is important to make the system stable when the lighting condition of the river scenery is changed.

To maximize the D_{bc}, the proposed method minimizes variance of the signal in the water (*W*) region while variance of the land (*L*) region is constant. Denoting variance of the region *R*={*W* or *L*} as σ_R^2, filter coefficients are determined so that the criterion:

$$L = \sigma_W^2 - \lambda\left(\sigma_L^2 - 1\right) \tag{10}$$

becomes minimum. It is described as the eigen-problem in which the eigen-equation is given by

$$\left(\varphi_L^{-1}\varphi_W - \lambda \mathrm{I}\right)F_{OPT\_1,2D} = \mathrm{O} \tag{11}$$

where

$$\boldsymbol{\varphi}_R = \begin{bmatrix} \theta_{0,R} & \theta_{1,R} & \theta_{2,R} \\ \theta_{1,R} & \theta_{0,R} & \theta_{1,R} \\ \theta_{2,R} & \theta_{1,R} & \theta_{0,R} \end{bmatrix}, \; R \in \{L, W\}$$

$$\theta_{k,R} = \sum_{(n_1,n_2)\in R} \frac{x(n_1+k, n_2)x(n_1,n_2)}{N_R}.$$

and $x(n_1,n_2)$ is the pixel value at location (n_1,n_2) in the region *R*. The optimum coefficients are given as the eigen-vector to the minimum eigen-value of $\boldsymbol{\varphi}_L^{-1}\boldsymbol{\varphi}_W$ in (11).

IV. Experimental Results

A. Signal Examples for Analysis

Fifteen samples of river scenery used for analysis are illustrated in Fig. 2. All of video signals are with 320x240 pixels and 30 frames per second under the difference of lighting conditions of river scenery. For example analysis of individual river scenery, four examples of different river scenery shown in Fig. 3 are applied. Sample A and B are video signal of the natural river scenery taken when weather is fine and snowing, respectively. And also, both of samples are modeled as model A and B respectively. "Models A" is an AR(1) model with correlation coefficient ρ_L=0.81 in land region and ρ_W=0.99 in water region. White noise is added to this model signal with SNR=31.6 [dB]. For "Model B", ρ_L=0.81, ρ_W=0.93and SNR=4.3 [dB].

B. The Ratio of the Distance between Classes and the Variance within Classes (D_{bc}/V_{wc}).

Fig. 4 comparatively illustrates the maximum value of D_{bc}/V_{wc} improving by horizontal 1D optimized filter with various taps. The appropriate number of taps of optimized filter is evaluated by referring to the maximum of D_{bc}/V_{wc}. The result of model A and B in Fig 4(a) compares with that of sample A and B in Fig. 4(b) respectively.

Fig. 4 (a) indicates the value of D_{bc}/V_{wc} applying horizontal 1D optimized filter with various taps for model A and B. Ten patterns under the same condition of either model A or B is applied for analysis. Diamond and triangle marker symbols are given as the average of D_{bc}/V_{wc} for ten patterns of model A and B respectively. Vertical straight line crossing each marker is defined as standard deviation of D_{bc}/V_{wc} for ten patterns of each model. It is found that the maximum of D_{bc}/V_{wc} is at two taps of optimized filter for model A and it is at four taps of optimized filter for model B.

Fig. 4 (b) illustrates a result of applying horizontal 1D optimized filter with various taps for sample A and B. Diamond and triangle marker symbols are given as a value of D_{bc}/V_{wc} for sample A and B respectively. It is found that the maximum of D_{bc}/V_{wc} is at two taps of optimized filter for sample A and it is at five taps of optimized filter for sample B.

The appropriate number of taps of optimized filter for sample A and model A is the same at two taps. For sample B and model B, a long tap filter does not evidently improve the value of D_{bc}/V_{wc}. The maximum of D_{bc}/V_{wc} for model B and sample B is at four and five taps of optimized filter respectively. It is not same due to the difference of natural simple image and its model.

Fig. 2 Fifteen samples of video signal for analysis.

Fig. 5 illustrates the effect of noise on the value of D_{bc}/V_{wc} by applying various types of spatial filter. Model A (ρ_L=0.81, ρ_W=0.99) is applied as an input signal. The different value of white noise is added to this model signal and indicated as the signal to noise ratio (SNR).

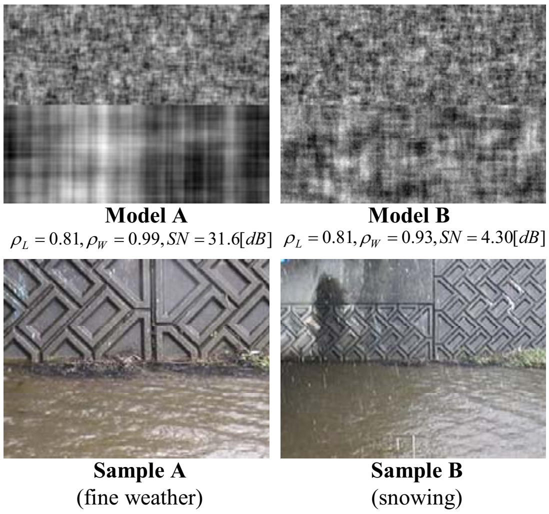
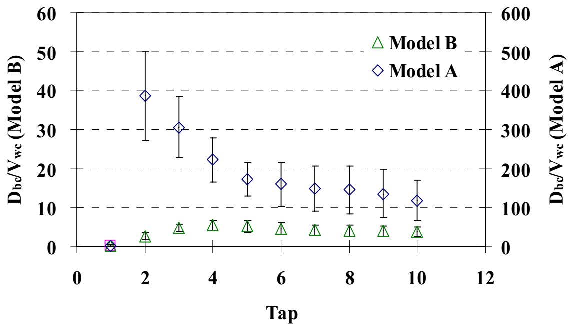
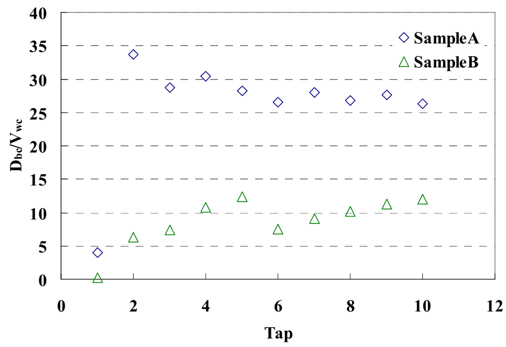


Fig. 3 Individual signal examples for analysis.



(a) Model A and B.



(b) Sample A and B.

Fig. 4 The maximum of D_{bc}/V_{wc} by horizontal optimized 1D filter with various taps.

Fig. 5 (a) is the result of applying various types of 1D spatial filter in "horizontal and vertical" direction. For comparison, the value of D_{bc}/V_{wc} applying vertical filters is lower than that by applying horizontal filters. It is confirmed that horizontal (_H) 1D filters are better than vertical ones. Therefore, we focus on only horizontal filters and consider which type of horizontal spatial filter is the best in aspect of the highest D_{bc}/V_{wc} along the range of SNR. In the SNR range of 3 to 15 dB (for higher noise), the three tap optimized filter "OPT_3Tap" is the best and nearly same as an existing band pass filter "BPF". However, in the SNR range of 15 to 33 dB (for lower noise), the two tap horizontal optimized filter "OPT_2Tap_H" with F_{OPT_1D} and an existing high pass filter "HPF" are the best for improving the maximum of D_{bc}/V_{wc}.

Fig. 5 (b) is for 2D filters. The three by three tap optimized filter "OPT_2D" with F_{OPT_2D} is the best in the SNR range of 18 to 33 dB (for lower noise). However, in the lower range of SNR, the value of D_{bc}/V_{wc} by the "OPT_2D"is slightly lower than that by the conventional 2D filters such as "Prewitt" and "Sobel".

C. The Error of Water Level Detection

Fig. 6 indicates the root mean square (RMS) of the average detection errors of water level in pixel. Fifteen samples of video signal in Fig. 2 are used. The maximum of D_{bc}/V_{wc} is also indicated to compare with the errors. Relationship between the errors and the maximum of D_{bc}/V_{wc} is discussed so that the optimized filter based on maximizing the distance between classes (D_{bc}) is effectively confirmed.

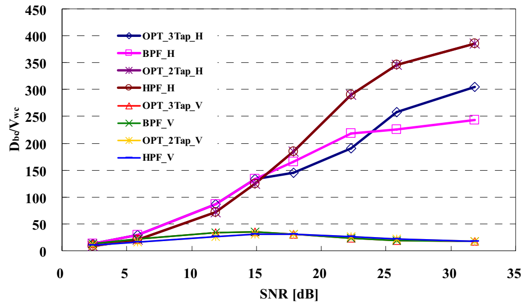
Fig. 6 (a) shows the detection error comparing with the maximum of D_{bc}/V_{wc} and applying various types of 1D filter. Each spatial filter is also comparatively utilized in "vertical" or "horizontal" direction. It is confirmed that horizontal 1D filters can reduce the error better than vertical 1D-filters in general. In case of horizontal 1D filters, the least detection error is performed by the Laplacian filter "LAP_3tap". The three tap 1D optimized filter "OPT_3tap"is the second of the least detection error. It is nearly the same as two tap 1D optimized filter "OPT_2tap" and existing high pass filter "HPF_H".

Fig. 6 (b) shows the detection errors by applying 2D filters. The three by three tap optimized filter "OPT_3×3Tap" is the best in case of the least detection error. The Prewitt and Sobel are the second best. The maximum of D_{bc}/V_{wc} inversely relates to the errors and it is confirmed again by the correlation coefficient in Fig. 6 (c).

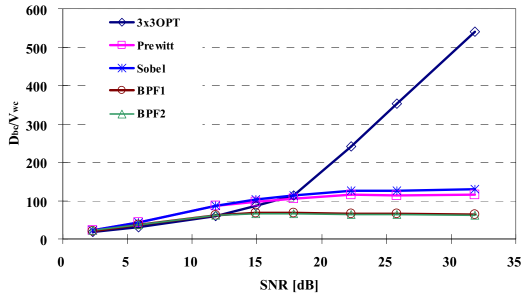
Fig. 6 (c) shows the correlation coefficient of the detection error and the maximum of D_{bc}/V_{wc} in Fig 6 (a) and (b). The shape of this data indicates an inverse relationship between the detection error and the maximum of D_{bc}/V_{wc}. It is a negative correlation equal to -0.89. It means that as the values of D_{bc}/V_{wc} increases, the detection error decreases.

Fig. 7 (a) indicates standard deviation (SD) of detection errors of the water level in pixel detected by the 1D filters. Fifteen kinds of video signals are used again. Average of the error was zero. It is confirmed that horizontal 1D filters can reduce the error than vertical 1D-filters in general. This fact supports the findings in [8]. It is also confirmed that the optimized filter "OPT_3tap" with $\mathbf{F}^T_{OPT\_1D}$ is almost same as the Laplacian filter "LAP_3tap" with $\mathbf{F}^T_{HP3}$, however better than the band pass filter "BPF_3tap" with $\mathbf{F}^T_{BP3}$. No significant superiority of the optimized filter was confirmed in case of three tap 1D filters.

Fig. 7 (b) indicates SD of the error detected by the 2D filters for the same video signals. It is confirmed that the optimized 2D filter is the best in respect of reducing SD of the errors.

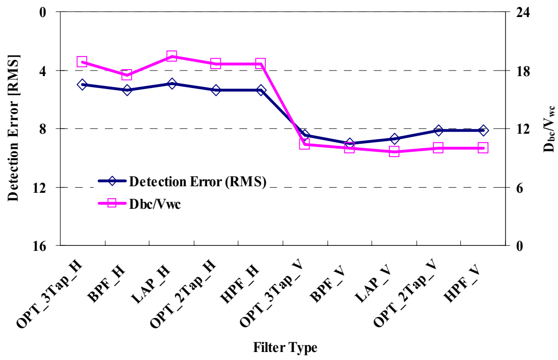


(a) Horizontal or vertical 1D filters

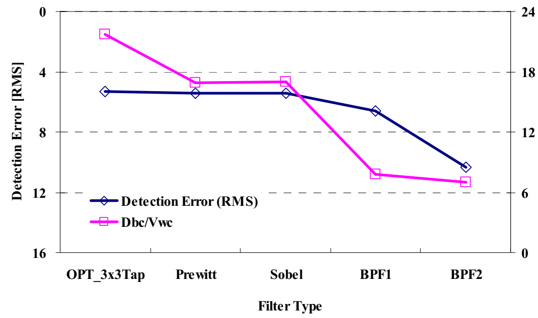


(b) 2D filters.

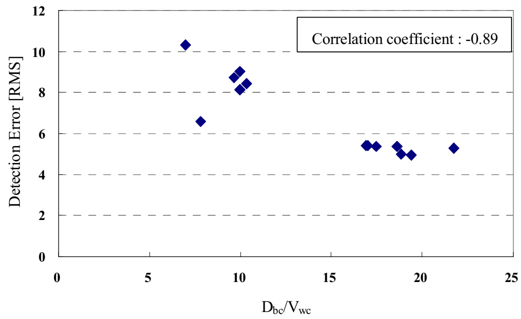
Fig. 5 The effect of noise on the maximum of D_{bc}/V_{wc} .



(a) 1D filters.

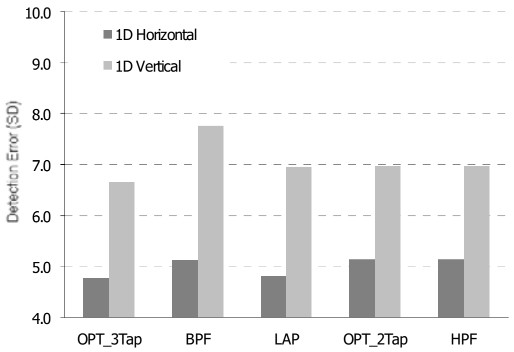


(b) 2D filters.

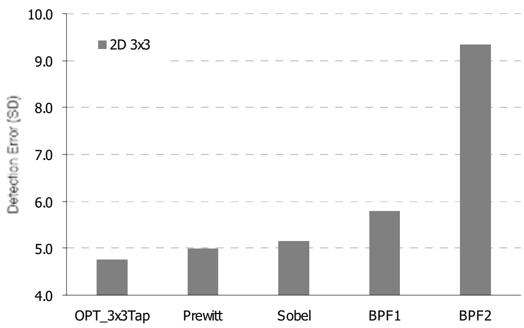


(c) Correlation coefficient.

Fig. 6 Relation between the detection error and D_{bc}/V_{wc}.



(a) 1D filters.



(b) 2D filters.

Fig. 7 The standard deviation of the errors of water level detection.

V. CONCLUSIONS

The optimized spatial FIR filter automatically maximizes the class distance of feature vector. It is useful to detect water level of various lighting conditions of river scenery. Water level detection algorithm based on synchronous frame addition and horizontal edge detection is evidently superior to the conventional algorithm.

ACKNOWLEDGMENT

This research is financially supported by Ministry of Internal Affairs and Communications, Japan as a SCOPE-C research project.

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