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水位検出フィルタの最適設計

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あらまし 本報告では、映像信号から流水領域を認識して水位を自動的に検出するためのフィルタの最適設計法を提案する。従来法として、「垂直」方向にエッジ検出を行い水平線として水面を検出する方法が報告されている。また、フレーム間の「差分」をとることで水蘚等による水路壁の汚れに対して堅牢化している。しかし、降雨雪粒子の誤検出により不安定となる。これに対し我々は、「水平」方向のエッジ検出とフレーム間の「加算」に基づく水位検出方法を既に提案している。本報告では、エッジ検出フィルタの最適化方法を提案し、その効果を確認する。

キーワード 水位, フィルタ, 映像, 認識, 設計

Optimum Filter Design for Water Level Detection

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Abstract This report proposes a design method of a digital filter to detect running water region in video signal. As a result of applying this filter, the water level of a river is automatically detected as a boundary between the land region and the water region. Conventional approaches have used the edge detector "vertically" to extract a horizontal line as running water surface. The frame "subtraction" is also accompanied to make it robust against disturbances. A new approach in this report applies the synchronous frame "addition" and "optimized" spatial filer to robustly detect the water level. Variance of pixel value along with each line of the filtered video is used as a feature value. Optimization procedure of the spatial filter coefficients is also proposed so that the system can be adaptive to changes of video shooting condition. Robustness against disturbances such as snow drops and superiority to conventional edge detectors are experimentally confirmed.

Keyword water level, filter, video, recognition, design

1. INTRODUCTION

So far, various kinds of river surveillance systems have been developed to prevent water disasters [1]. The "telemeter", which is installed by the government, collects information about water level of rivers at several points [2]. However, the number of observation points is limited to a few principal rivers.

Video surveillance systems have been increasing due to progress of compression technology such as MPEG and widely expanding their coverage area. However, Most of them can not automatically detect water level of a river.

Image recognition algorithms for water level detection have been proposed by Takagi [3,4]. They are based on detecting a bending point of a diagonal line on a measuring board. However, their performance is sensitive to stains on the line and it is strictly controlled by an administrator to install any obstacle such as the board in the water.

A video processing algorithm without setting any board has been proposed by Tsunashima [5]. It detects a horizontal line as surface of the running water with the vertical edge detector. It also employs subtracting frames to make it robust against stains on the wall of a channel. However, it is sensitive to moving disturbances such as rain or snow drops.

This report proposes a robust water detection algorithm based o adding frames and spatial filtering. Optimization of the filter is also proposed so that is becomes adaptive to scene changes. Its performance is experimentally compared to the conventional Sobel or Prewitt operators.

2. WATER LEVEL DETECTION

2.1. Algorithm

Some examples examined in this report are indicated in figure 1. Model A and B are AR(1) model with autocorrelation ρ_W in water region and ρ_L in land region. White noise is added with the SNR indicated. Samples A and B taken with a SONY "handycam" are with 320 x 240 [pixels] and 30 [frames/sec].

Video scenery is assumed to contain 1) running water region with no-standing waves in lower part and 2) land region with standing textures as shown in figure 2(a). It is preferable for the detection that the statistical characteristics are uniform within each region.

STEP_1: Produce a still image by averaging (adding) continuous (around thirty [6]) frames. As a result of this step, high frequency components in the water region are reduced as illustrated in figure 2(b).

STEP_2: Emphasize the statistical difference between the two regions by the spatial filter in 2.3. A result is indicated in figure 2(c) for example.

STEP_3: Calculate logarithm of variance along with each line of the image as a feature value (*FV*), one dimensional feature vector in this case, as illustrated in figure 2(d). Search the point which maximizes the ratio of the distance between classes (D_{bc}) and the variance within classes (V_{wc}) as the water level. The ratio is defined by

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

where *W* and *L* denote Water region and Land region, *P* is the probability, s_i and m_i for $i=\{W \text{ or } L\}$ are standard deviation and average of *FV* in each region respectively.

2.2. Spatial Filters

Denoting the transfer function of a spatial FIR filter by equation (2), the filters (1) - (6) summarized below are used in the experiments in **3**.

$$H(z_1, z_2) = \left[z_2^{-1} \quad 1 \quad z_2\right] \mathbf{H} \left[z_1^{-1} \quad 1 \quad z_1\right]^T \qquad (2)$$

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{0,1} & h_{-1,1} \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ h_{1,-1} & h_{0,-1} & h_{-1,-1} \end{bmatrix},$$

1) 1D High Pass filter (horizontal or vertical)

$$\mathbf{H}_{HPF\_2tap} = \begin{bmatrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad or \quad \begin{bmatrix} 0 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

2) 1D Band Pass filter (horizontal or vertical)

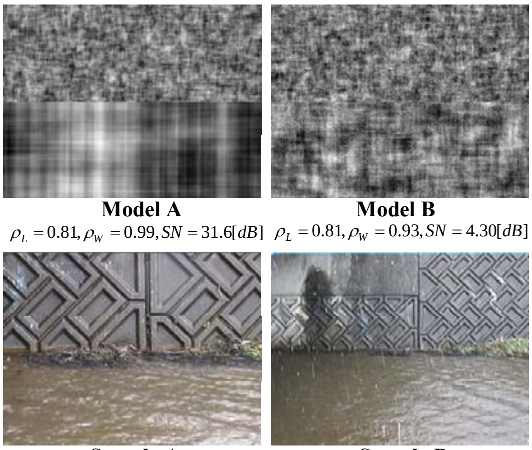
$$\mathbf{H}_{BPF\_3tap} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & -1 \\ 0 & 0 & 0 \end{bmatrix} \quad or \quad \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

3) 1D Laplacian filter (horizontal or vertical)

$$\mathbf{H}_{LAP\_3tap} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{bmatrix} \quad or \quad \begin{bmatrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

4) 2D Band Pass filters (diagonal)

$$\mathbf{H}_{BPF1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}, \quad \mathbf{H}_{BPF2} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$



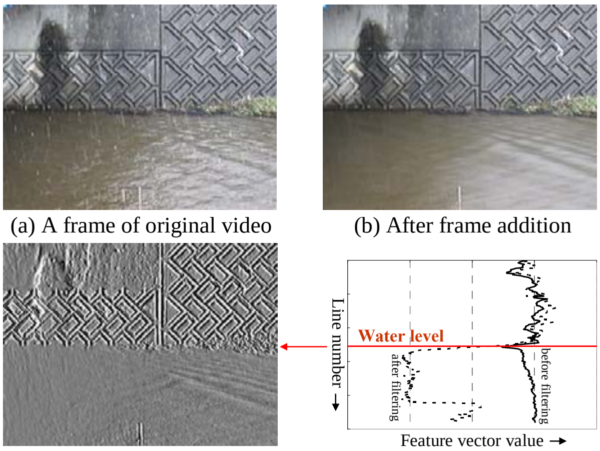
Model A $\rho_L = 0.81, \rho_W = 0.99, SN = 31.6[dB]$

Model B $\rho_L = 0.81, \rho_W = 0.93, SN = 4.30[dB]$

Sample A (fine weather)

Sample B (snowing)

Figure 1 Tested signals.



(a) A frame of original video

(b) After frame addition

(c) After spatial filtering

(d) Detected water level

Figure 2 Signal processing of the proposed system.

5) 2D conventional operators

$$\mathbf{H}_{Prewitt} = \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}, \quad \mathbf{H}_{Sobel} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

6) Optimized filters (1D or 2D)

$$\mathbf{H}_{OPT\_3tap} = \begin{bmatrix} 0 & 0 & 0 \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ 0 & 0 & 0 \end{bmatrix} \quad \mathbf{H}_{OPT\_3x3} = \begin{bmatrix} h_{1,1} & h_{0,1} & h_{-1,1} \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ h_{1,-1} & h_{0,-1} & h_{-1,-1} \end{bmatrix}$$

2.3. Optimization of the spatial filter

In this report, a spatial filter is designed so that it maximizes the numerator D_{bc} of equation (1). The denominator V_{wc} is considered to be dependent on non-uniform statistics within each region. It aims at gaining robustness against the latter by maximizing the former.

Denoting variance of the region R={W or L} as σ_R^2, filter coefficients are determined so that the ratio

$$I = \sigma_W^2 / \sigma_L^2 \tag{2}$$

becomes minimum. As a result, its logarithm

$$I' = \log I = m_W' - m_L' \tag{3}$$

also becomes maximum. Denoting variance of the i-th line of the image as σ_i^2 and the number of lines in the region as N_R, their relation is described as

$$m_R' = \log \sigma_R^2 = \log \sum_{i \in R} \frac{\sigma_i^2}{N_R}, \quad R \in \{W, L\} \cdot \tag{4}$$

On the other hand, D_{bc} contains the factor

$$D = (m_W - m_L)^2 \tag{5}$$

where

$$m_R = \log \prod_{i \in R} \left(\sigma_i^2\right)^{\frac{1}{N_R}}, \quad R \in \{W, L\} \cdot \tag{6}$$

Therefore, maximizing distance between the arithmetic means in equation (4) is equivalent to that between the geometric means in equation (6). As a result, the problem is solved by the Lagrange's undetermined multiplier method. It minimizes the term

$$L = \sigma_W^2 + \lambda\left(\sigma_L^2 - 1\right) \tag{7}$$

and it is described as the eigen-problem.

For example, denoting a 3 tap 1D horizontal filter as

$$H(z_1) = \mathbf{H}_{OPT\_3tap}\begin{bmatrix} z_1^{-1} & 1 & z_1 \end{bmatrix}^T, \tag{8}$$

the filter coefficients

$$\mathbf{H}_{OPT\_3tap} = \begin{bmatrix} h_{1,0} & h_{0,0} & h_{-1,0} \end{bmatrix} \tag{9}$$

are given by the eign-equation

$$\left(\boldsymbol{\varphi}_L^{-1}\boldsymbol{\varphi}_W - \lambda \mathbf{I}\right)\mathbf{H} = \mathbf{O} \tag{10}$$

where

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

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

and $x(n_1,n_2)$ is the pixel value at location (n_1,n_2). The optimum coefficients is the eigen-vector to the minimum eigen-value of $\boldsymbol{\varphi}_L^{-1}\boldsymbol{\varphi}_W$. Optimum 1D vertical filter or 2D filter is similarly determined by the procedure above.

3. EXPERIMENTAL RESULTS

3.1. Value of the feature vector

Figure 3 indicates FV of each line after adding frames and spatial filtering for "Model A". The model emulates ordinary land scenery and water region with reduced high frequency components after the frame averaging (addition).

Figure 3(a) is a result of applying "horizontal" 1D filters. It is confirmed that the three tap optimized filter (OPT_3Tap) is the best for maximizing D_{bc}. The Laplacian (LAP) is almost the same.

Figure 3(b) is a result of "vertical" 1D filters. No significant difference among filters is observed in respect of maximizing D_{bc}. On the other hand, V_{wc} is increased when it is compared to "horizontal" case. Namely, "horizontal" edge detection, band pass or high pass, is better than "vertical". It agrees with experimental results in [6].

Figure 3(c) is a result of 2D filters. The three by three tap optimized filter (OPT_3x3) is confirmed to be the best followed by the diagonal band pass filters (BPF1, BPF2). The conventional edge detection filters Sobel and Prewitt are inferior to the optimized one.

3.2. Distance between classes

Figure 4(a) summarizes D_{bc} for all the images in figure 1. Horizontal (_H) 1D filters are better than vertical (_V) ones for sample A and B. Situation is opposite for model A. No difference for model B. It should be reconsidered how to make a model image.

Figure 4(b) is for 2D filters. The three by three tap optimized filter (OPT_3x3) is the best for all cases. It is also confirmed that the proposed method is superior to the conventional Sobel and Prewitt.

Figure 4(c) is a result of horizontal 1D optimized filter with various taps. As the number of tap increases, D_{bc} is gradually increased. In this case, a long tap filter does not dramatically improve D_{bc}.

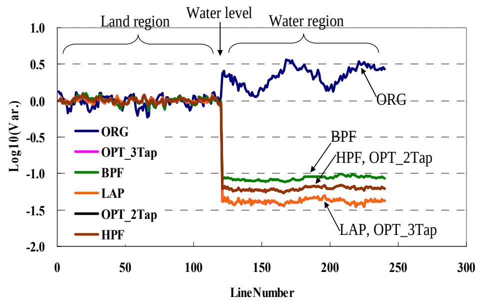
3.3. Spectrum

Figure 5(a) and 6(a) are an example of amplitude frequency characteristics of model A and sample A respectively. Average of lines in land region is plotted as well as water region. It is confirmed that water region has less energy in high frequency after the frame addition.

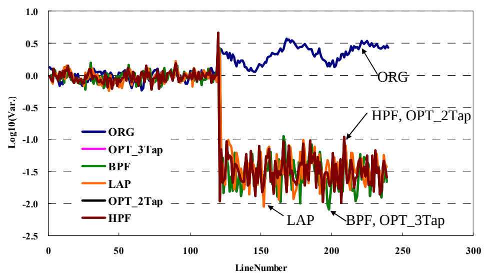
Figure (b) is a difference (subtraction in logarithm and ratio in linear) between land region and water region. The difference exists in middle frequency in this case.

Figure (c) is the frequency response of the optimized filters. These filters are considered to maximize D_{bc} by emphasizing the difference in the figure (b).

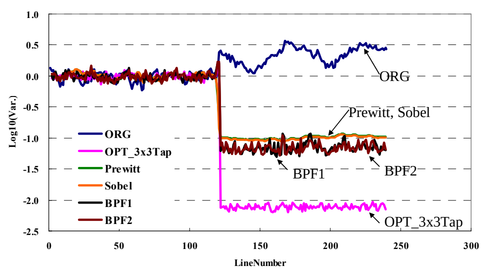
Figure 7 is the frequency response of the conventional filters. It is the next best solution to select one of these filters depending on input video scenery when hardware complexity, necessary to calculate equation (10), should be excluded.



(a) Horizontal 1D filter

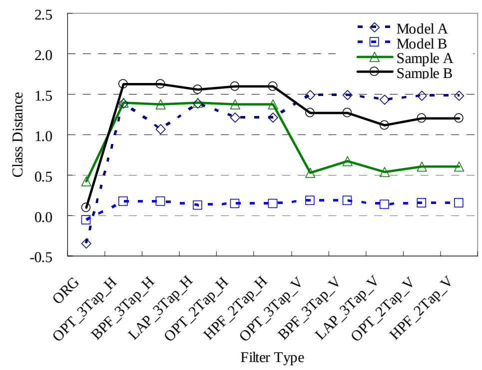


(b) Vertical 1D filter

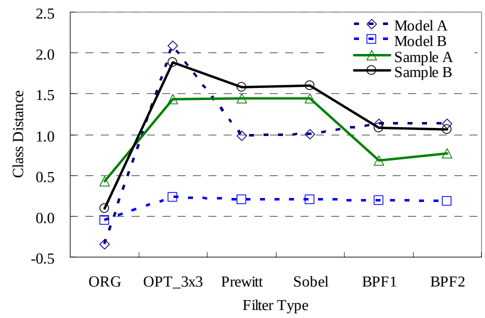


(c) 2D filter

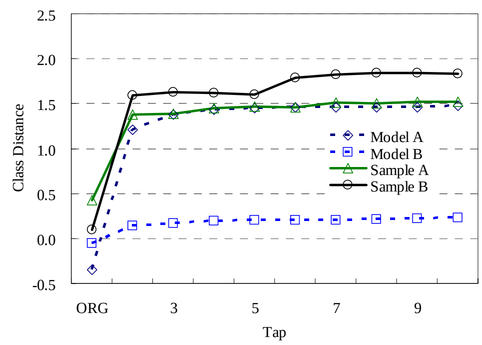
Figure 3 Feature value (*FV*) for "Model A"



(a) Horizontal or vertical 1D filters.

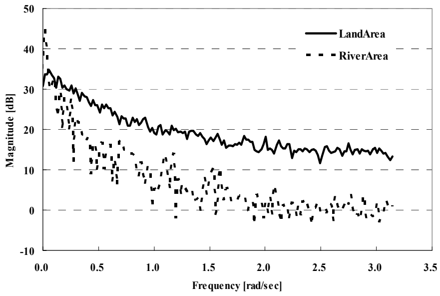


(b) 2D filters.

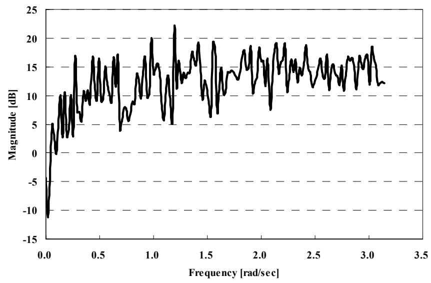


(c) Horizontal 1D filters with various tap.

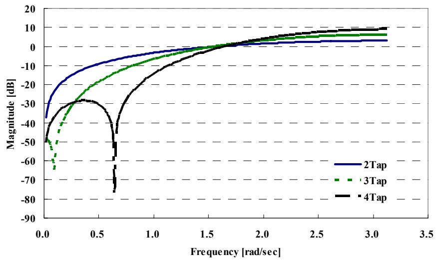
Figure 4 Distance between classes (D_{bc}).



(a) Land region and Water region.



(b) Difference between land and water.



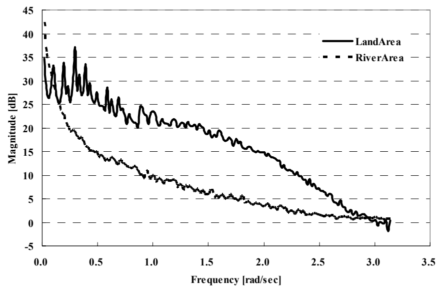
2Tap [-0.7071   0.7071]

3Tap [0.5021   -1.0   0.5021]

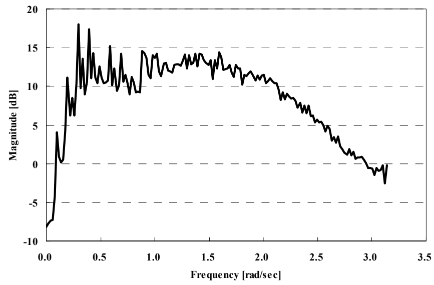
4Tap [0.3846   -1.0   1.0   -0.3846]

(c) Optimized 1D filters.

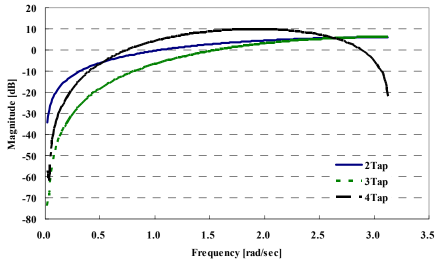
Figure 5 Amplitude frequency characteristics for "**Model A**"



(a) Land region and Water region.



(b) Difference between land and water.



2Tap [1.0   -1.0]

3Tap [-0.5002   1.0   -0.5002]

4Tap [-1.0   0.9989   0.9989   -1.0]

(c) Optimized 1D filters.

Figure 6 Amplitude frequency characteristics for "**Sample A**"

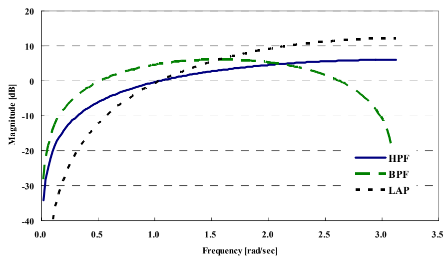


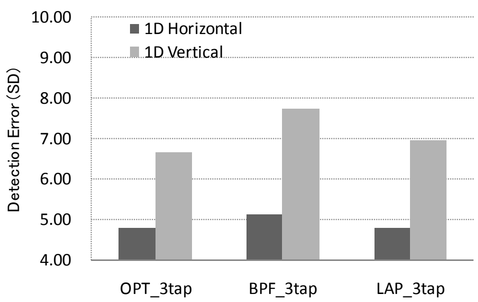
Figure 7 Amplitude frequency characteristics of 1D conventional filters.

3.4. Water level detection

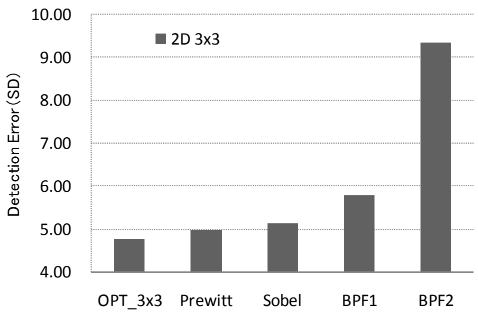
Figure 8(a) indicates standard deviation (SD) of errors of the water level in pixel detected by the 1D-filters. Fifteen kinds of video signals were used. Average of the error was zero. It is confirmed that horizontal 1D-filters can reduce the error than vertical 1D-filters in general. This fact supports the findings in [6]. It is also confirmed that the optimized filter (OPT_3tap) is almost same as the Laplacian (LAP_3tap), however better than the band pass filter (BPF_3tap). No significant superiority of the optimized filter was confirmed in case of 3 tap 1D filters.

Figure 8(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.

Error of the detected water level can be incidentally zero even though the two classes are not well separated (equation (1) is not large enough). The optimization in this paper maximizes the numerator D_{bc} of equation (1), however does not control the denominator V_{wc}. Maximizing the class distance D_{bc} can be considered to make the system robust to turbulences.



(a) 1D filter



(b) 2D filter

Figure 8 Water level detection errors for 15 samples.

4. CONCLUSIONS

This report proposed a water level detection algorithm based on "spatial filtering" and "frame addition". Optimization procedure of the spatial filter was introduced. Optimized 2D filter's superiority to the conventional 2D edge detection operators, Prewitt and Sobel, was confirmed in respect of maximizing distance between classes. In case of using a 1D filter, horizontal edge detection was found to be better than vertical one to maximize distance between classes and not to increase variance within classes. Relation between the number of pixels and the variance within classes will be investigated in the near future.

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