WATER LEVEL DETECTION FROM VIDEO WITH FIR FILTERING

Masahiro IWAHASHI Sakol UDOMSIRI

Department of Electrical Engineering,
Nagaoka University of Technology
940-2188, Nagaoka, Japan

*Abstract***— This paper proposes how to detect water level from a video signal for use of automatic river surveillance. The water level is recognized as a boundary line between the land region and the water region. A conventional method uses a "vertical" edge detector to extract a horizontal line as the running water surface. "Subtraction" of frames is also accompanied to make it robust to horizontal line like disturbances. 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. Optimization of the edge detection filter is also discussed so that the system becomes robust to changes of lighting condition.**

Keywords; water level, video, filter, detection

I. INTRODUCTION

Various kinds of river surveillance systems have been developed to prevent water disasters [1]. 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. Video surveillance systems have been increasing due to progress of compression technology such as MPEG and widely expanding their coverage area. MPEG 4 has a feature to extract objects [3]. However, it is not tuned to automatically detect the water level.

Image recognition algorithms for water level detection have been proposed by Takagi [4,5]. 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 [6]. 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. [7]. 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.

In this paper, we propose a water level detection algorithm based on "horizontal" edge detection and frame "addition". Variance of each horizontal line of a filtered video frame is used as a feature value. 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 the edge detection filter is also discussed so that the system becomes adaptive to changes of lighting condition.

II. WATER LEVEL DETECTION FROM VIDEO

A. Video Signal to be Processed

It is assumed that a video signal to be processed for water level detection is taken so that it contains 1) running water region in lower part and 2) land region with textures in upper part and 3) boundary between the two regions is the water level to be detected. A part of a river surveillance video can be used after properly selecting a region, cutting it and processing it with the affine transform. An example is illustrated in figure 1.

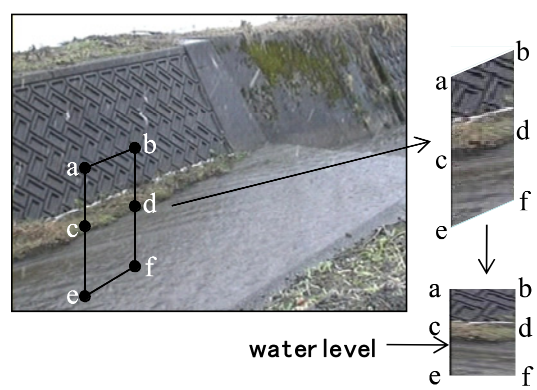


Fig.1 A video signal to be used for water level detection.

B. *Existing Approach*

A conventional method in [7] applies a "vertical" edge operator to detect horizontal lines. Examples of the operator are given by

$$\begin{cases} HP2 = [-1 \quad 1]^T \\ BP3 = [-1 \quad 0 \quad 1]^T \\ HP3 = [1 \quad -2 \quad 1]^T \end{cases} . \tag{1}$$

Using the z-transform, these filters are denoted by the filter coefficient matrix:

$$\mathbf{F}_{HP2} = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \quad \mathbf{F}_{BP3} = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}, \quad \mathbf{F}_{HP3} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{bmatrix} \tag{2}$$

where

$$H(z_1, z_2) = \left[z_2^{-1} \quad 1 \quad z_2\right] \mathbf{F} \left[z_1^{-1} \quad 1 \quad z_1\right]^T . \tag{3}$$

In case of the conventional method, the filter below:

$$\mathbf{F}_{BP3*LP5} = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \tag{4}$$

is applied. This is a convolution of the vertical edge detector "$BP3$" (three tap band pass filter) in equation (1) and the five tap low pass filter "$LP5$" defined by

$$LP5 = [1 \quad 1 \quad 1 \quad 1 \quad 1]. \tag{5}$$

C. *Frequency Characteristics of the Egde Detectors*

Characteristics of the edge operators are calculated from the z-transform. For example, in case of the filters in equation (1) and (5), frequency amplitude characteristics (impulse responses) are

$$\begin{aligned} \left|H_{HP2}(e^{j\omega_1}, e^{j\omega_2})\right| &= 2\sin\frac{\omega_2}{2} \\ \left|H_{BP3}(e^{j\omega_1}, e^{j\omega_2})\right| &= 2\sin\omega_2 \\ \left|H_{HP3}(e^{j\omega_1}, e^{j\omega_2})\right| &= 2(1-\cos\omega_2) \\ \left|H_{LP5}(e^{j\omega_1}, e^{j\omega_2})\right| &= 1 + 2(\cos\omega_1 + \cos 2\omega_1) \end{aligned} . \tag{6}$$

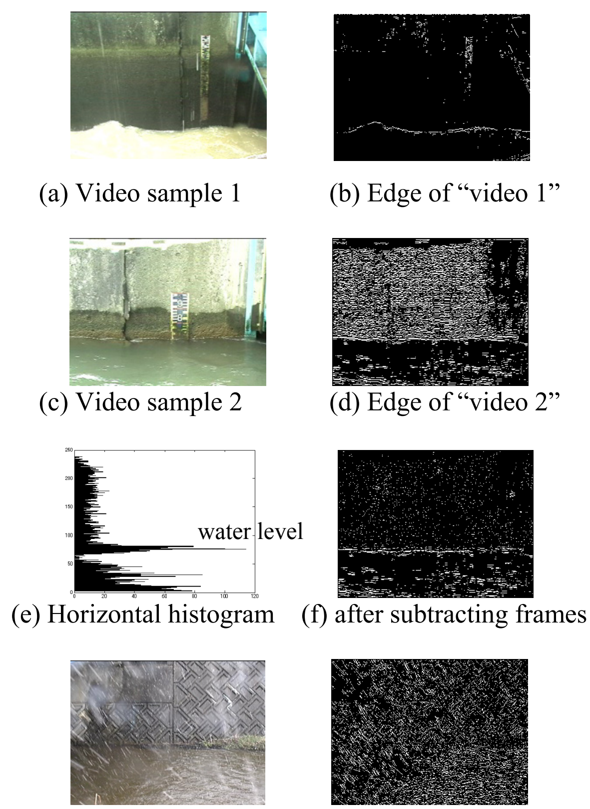
Namely, equation (4) is a vertically band pass and horizontally low pass filter.

D. *Problem of the Existing Method*

Examples of the video signal processing are illustrated in figure 2. Applying the "vertical" edge detector to the video sample 1 in figure 2 (a), water surface is detected as indicated in figure 2 (b). Filtered pixel value is quantized into binary value in which an edge is indicated as "white" pixel in figure 2 (b). On the contrary, in case of the video sample 2, it becomes almost impossible to determine the water surface. This is because the edge operator detects not only the surface but also horizontal line like disturbances.

In the conventional method, "subtraction" of two frames at different time is applied to get rid of these disturbances. As a result, the horizontal line like textures in the land region disappears and the texture due to the moving water surface remains as illustrated in figure 2 (f). Counting the number of edges of each line, the horizontal histogram is generated as indicated in figure 2 (e). The water level is detected as vertical location of the horizontal peak (the maximum number of edges) in the histogram.

However, in case of snowing situation, this method does not properly work as indicates in figure 2 (h). This is because the frame "subtraction" detects moving objects such as snow drops.



(a) Video sample 1 (b) Edge of "video 1"

(c) Video sample 2 (d) Edge of "video 2"

(e) Horizontal histogram (f) after subtracting frames

(g) Video sample 3 (h) after subtracting frames

Fig.2 Existing approach and its problem.

III. PROPOSED METHOD

A. *Frame Addition*

The proposed algorithm is based on "horizontal" edge detection and frame "addition". By adding some frames, moving objects such as snow drops and waves of running water becomes blurred 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. Examples are illustrated in figure 3 (b). In this example, thirty frames during one second are added. This number is experimentally determined in [8]. Figure 4 illustrates frequency amplitude characteristics (spectrum) of the land region and the water region. Each of them represents 1D spectrum averaged over lines in the region. It is confirmed that the frame addition reduces high frequency components of the water region and does not in the land region.

B. *Horizontal Edge Detection (Spatial Filtering)*

Next, "horizontal" edge detection is applied so that the difference of the spectrum between the two regions is emphasized and detected. To detect edges vertically, transpose of the filter coefficient matrix **F** in equations (2) and (4) are used. In addition to these equations, we also investigate the filters:

$$\mathbf{F}^{T}_{Prewitt} = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}, \quad (7)$$

$$\mathbf{F}^{T}_{Sobel} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}. \quad (8)$$

These are the "Prewitt" operator and the "Sobel" operator respectively. Figure 3 (c) illustrates an example of applying the "*BP*3" filter horizontally to the image in figure 3 (b).

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. The feature vector can be multi-dimensional value calculated by the Gabor filter bank, for example in [9-11]. In this paper, variance of each horizontal line is used as one dimensional simply calculated feature vector value.

Example of the feature value is indicated in figure 3 (d). 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

$$\frac{D_{bc}}{V_{wc}} = \frac{P_L P_W (m_L - m_W)^2}{P_L s_L^2 + P_W s_W^2} \quad (9)$$

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}. In equation (9), 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 the distance between the classes D_{bc}.

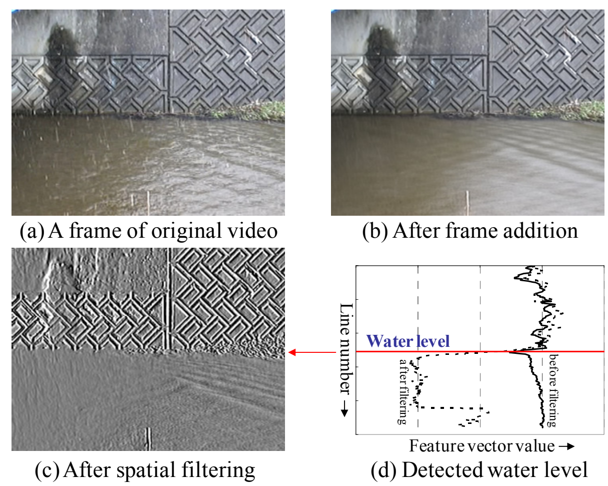


Fig.3 The proposed water level detection procedure.

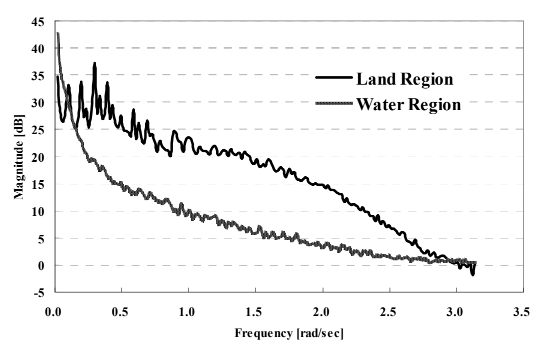


Fig.4 Frequency amplitude characteristics.

D. Optimizatio of the Filter

In this paper, optimization of the filter is also investigated. The distance between the classes D_{bc} in equation (9) is used as a criterion for the optimization. This can be used also for selecting the best filter among some given filters. 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 under the condition that 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.

For example, in case of 1D horizontal filter is used in which the filter coefficient matrix is defined by

$$\mathbf{F}^T_{OPT\_1D} = \begin{bmatrix} 0 & 0 & 0 \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ 0 & 0 & 0 \end{bmatrix}, \tag{11}$$

the eigen-equation is given by

$$\left(\boldsymbol{\varphi}_L^{-1}\boldsymbol{\varphi}_W - \lambda \mathbf{I}\right)\mathbf{H} = \mathbf{O} \tag{12}$$

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 equation (12). In case of 2D filter, the filter coefficients matrix:

$$\mathbf{F}^T_{OPT\_2D} = \begin{bmatrix} h_{1,1} & h_{0,1} & h_{-1,1} \\ h_{1,0} & h_{0,0} & h_{-1,0} \\ h_{1,-1} & h_{0,-1} & h_{-1,-1} \end{bmatrix} \tag{13}$$

of 3x3 tap for example, is similarly determined by the procedure described above.

IV. EXPERIMENTAL RESULTS

A. Signal Examples for Analysis

Figure 5 indicates four sample signals for analysis in this section. “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 at SNR=31.6 [dB]. For “model B”, ρ_L=0.81, ρ_W=0.93 and SNR=4.3 [dB]. “Sample A” and “sample B” are with 320x240 pixels and 30 frames per sec under different weather condition.

B. Value of the feature vector

Figure 6 indicates feature value of each line after the frame addition and the spatial filtering for "Model A". The model emulates ordinary land scenery and water region with reduced high frequency components after the frame addition.

Figure 6 (a) is a result of applying “horizontal” 1D filters. It is confirmed that the three tap optimized filter “OPT_3tap” with $\mathbf{F}^T_{OPT\_1D}$ is the best for maximizing D_{bc}. A conventional Laplacian filter “*LAP*” with $\mathbf{F}^T_{HP3}$ is almost same.

Figure 6 (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 filtering, is better than “vertical” one. It agrees with experimental results in [8].

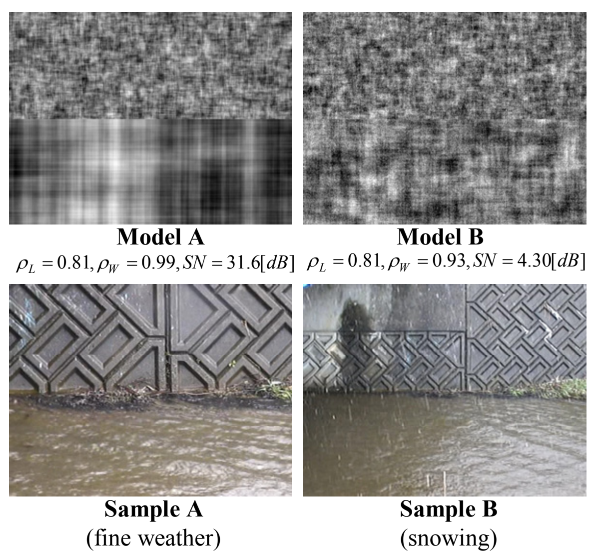


Fig.5 Signal examples for analysis.

Figure 6 (c) is a result of 2D filters. The three by three tap optimized filter "OPT_2D" with $\mathbf{F}^T_{OPT\_2D}$ is confirmed to be the best followed by the diagonal band pass filters "BPF1" with $\mathbf{F}^T_{DF1}$ and "BPF2" with $\mathbf{F}^T_{DF2}$:

$$\mathbf{F}^T_{DF1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}, \quad \mathbf{F}^T_{DF2} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix}. \tag{11}$$

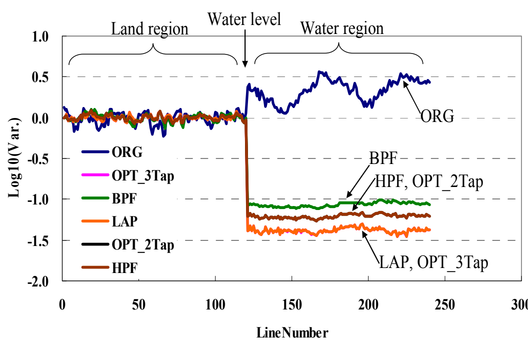
The conventional edge detection filters Sobel with $\mathbf{F}^T_{Sobel}$ and Prewitt with $\mathbf{F}^T_{Prewitt}$ are inferior to the optimized one.

C. *Distance between Classes*

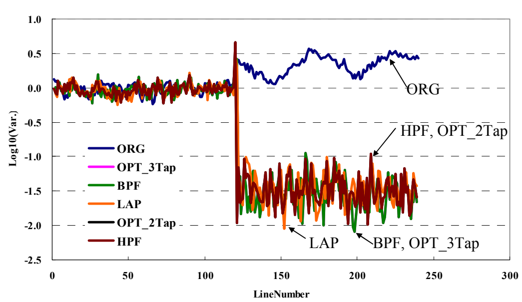
Figure 7 (a) summarizes distance between the classes D_{bc} for all the images in figure 5. Horizontal (_H) 1D filters are better than vertical (_V) ones for sample A and B. Situation is opposite for model A. There is no difference for model B.

Figure 7 (b) is for 2D filters. The three by three tap optimized filter "OPT_2D" with $\mathbf{F}^T_{OPT\_2D}$ is the best for all cases. It is also confirmed that the proposed method is superior to the conventional Sobel and Prewitt filters.

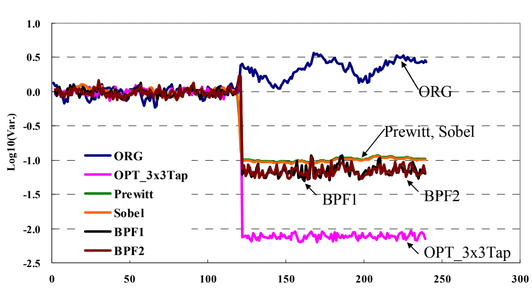
Figure 7 (c) is a result of horizontal 1D optimized filter with various taps. As the number of tap increases, D_{bc} is gradually increased. In this case, a long tap filter does not dramatically improve D_{bc}.



(a) Horizontal 1D filter

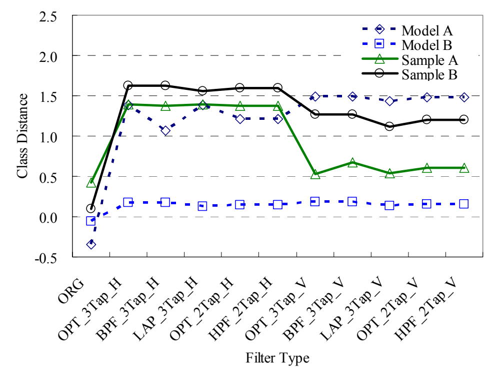


(b) Vertical 1D filter

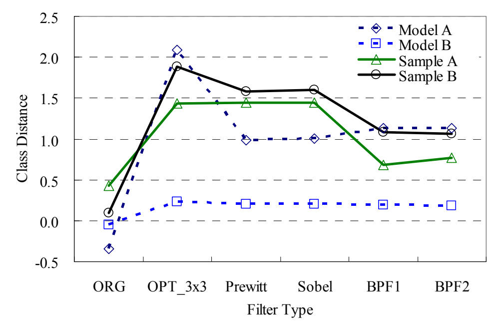


(c) 2D filter

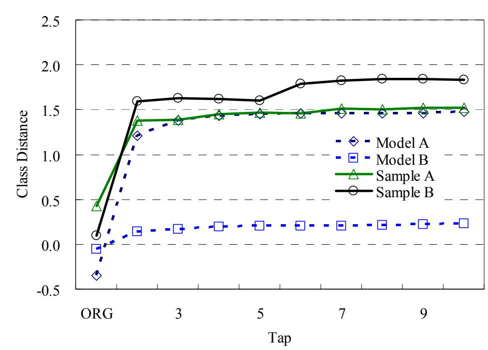
Fig.6 Feature value of "Model A"



(a) Horizontal or vertical 1D filters.



(b) 2D filters.



(c) Horizontal 1D filters with various tap.

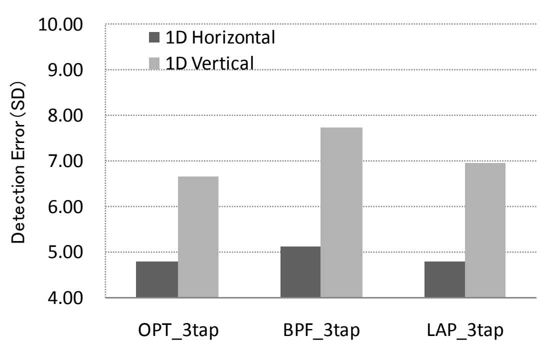
Figure 7 Distance between classes (D_{bc}).

D. Water Level Detection

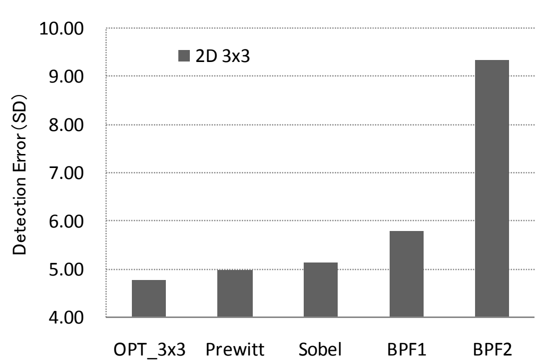
Figure 8 (a) indicates standard deviation (SD) of errors of the water level in pixel detected by the 1D filters. Fifteen kinds of video signals were used. Average of the error was zero. It is confirmed that horizontal 1D filters can reduce the error than vertical 1D-filters in general. This fact supports the findings in [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.

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. The optimization in this paper maximizes the numerator D_{bc}, 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 filters



(b) 2D filters

Figure 8 Water level detection errors for 15 samples.

V. CONCLUSIONS

This paper 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.

ACKNOWLEDGMENT

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