Tracking and removal of suspended matter from underwater video images

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ABSTRACT

We propose a method for obtaining clear underwater images by tracking the motion of suspended matter from video images captured in water and by separating the images into foreground and background. We assume that input images are the superposition of a foreground and a background, and constructed a transition model and the observation model. An input image is divided into patches and tracking of the foreground in each patch is performed while applying Kalman filter to separate the input images into the foreground and the background. From the result of the experiment using simulated images, we confirmed that the background images were successfully estimated and a region that was moving slowly was also recognized as a part of the background.

Keywords: Kalman filer, image restoration, noise removal, background segmentation

1. INTRODUCTION

In fishing industry, resource surveys using underwater images are widely conducted. Since the result has a large influence on the preservation of fishery resource and fishing, it is required to improve the accuracy [1]. However, underwater images are cloudy due to sand and seaweed and it is required to obtain clear images for accurate survey.

To solve this problem, methods for obtaining clear underwater images by image processing have been proposed [2-4], but there are few studies for removing suspended matter in the water such as sand, seaweed, and microorganisms.

On the other hand, methods for removing noise and for separating foreground and background from video images have been proposed [5]. By regarding sand and seaweed suspending in water as noise or foreground, these methods can be used for removing suspended matter in the water.

Therefore, we propose a method for obtaining clear underwater images by tracking the motion of suspended matter from video images captured in water and by separating foreground and background. Figure 1 shows one frame of underwater video images that were captured by a fixed-point camera installed on the seabed. Seaweed, garbage, sand and so on are always flowing in the images.

Figure 1. Underwater image

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2. PROPOSED METHOD

We assume that input images are the superposition of a foreground and a background. The foreground is moving fast and the moving directions are locally uniform. The background is changing slowly. Then, the transition model of the video images is written as Eq. (1) and the observation model as Eq. (2).

$$\begin{pmatrix} B_k(x,y) \\ F_k(x,y) \end{pmatrix} = \begin{pmatrix} B_{k-1}(x,y) \\ F_{k-1}\left(x+u_k^{(i)}, y+v_k^{(i)}\right) \end{pmatrix} + \begin{pmatrix} \varepsilon_{B,k}(x,y) \\ \varepsilon_{F,k}(x,y) \end{pmatrix} \quad (1)$$

$$I_k(x,y) = \begin{pmatrix} 1 & 1 \end{pmatrix} \begin{pmatrix} B_k(x,y) \\ F_k(x,y) \end{pmatrix} + n_k(x,y) \quad (2)$$

Here, $I_k(x,y)$ is the input image at frame k, $F_k(x,y)$ is the foreground image, and $B_k(x,y)$ is the background image. The changes of foreground and background is $\varepsilon_{F,k}(x,y) \sim N(0,\sigma_F^2)$ and $\varepsilon_{B,k}(x,y) \sim N(0,\sigma_B^2)$, respectively. Since the observed image contains noise, the superposition of a foreground and a background added with the observation noise $n_{M,k}(x,y) \sim N(0,\sigma_M^2)$ is observed.

An input image is divided into N patches as shown in Fig. 2(a). P_i is the i-th patch and $(x,y) \in P_i$ in Eq. (1). $\left(u_k^{(i)}, v_k^{(i)}\right)$ is the movement of foreground in P_i from frame $k-1$to frame k. It is possible to track the region by finding $\left(u_k^{(i)}, v_k^{(i)}\right)$.

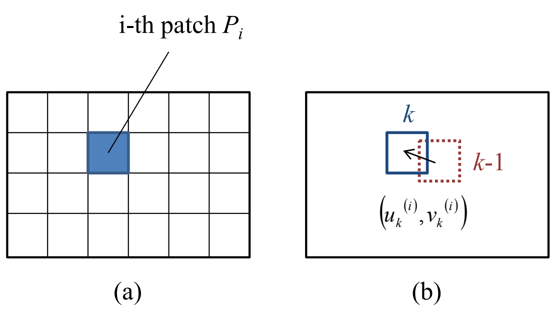

Figure 2. Division of input image and tracking

The algorithm to estimate the background and the foreground images is shown below.

1. Initialize B_0 by the average of I_k over several frames.
2. Initialize F_0 by $I_k - B_0$.
3. Move $\left(u_k^{(i)}, v_k^{(i)}\right)$ in the search range for a certain i.
4. Update B_k and F_k in the region $(x,y) \in P_i$.
5. Take $\left(u_k^{(i)}, v_k^{(i)}\right)$ that minimizes $\sum (I_k(x,y) - B_k(x,y) - F_k(x,y))^2$ in the region above.
6. Perform steps 3 to 5 in each i.
7. Move to the next frame.

3. EXPERIMENT

Since the real seabed images are noisy and suspended matter is moving fast, we first confirmed if the proposed algorithm worked properly using simulated images. The simulated images are captured using a USB monochrome camera Firefly MV, with an image size of 320×240 pixels and a frame rate of 120 fps. Gelatin noodles that are crushed to less than 1 mm are put in a fish tank containing water, and the water is stirred to simulate the seabed environment. An image “Bridge” from the SIDBA (Standard Image Data-BAse) is put on the outer wall of the fish tank as background. In addition, an image “Lenna” from SIDBA is inserted between the background and the outer wall and is moved slowly to simulate the change of background. A sequence of images (300 frames) is processed using the proposed method. The parameters are set to $\sigma_B^2 = 1$, $\sigma_F^2 = 0.01$, and $\sigma_M^2 = 100$, and the patch size is set to 10×10 pixels.

Figure 3 shows the result. Input images are in the top row, the background images separated from the input images using the proposed method are in the middle row, and the foreground images separated from the input images are in the bottom row. From the result, we can confirm that the background images were successfully estimated and the moving Lenna image was recognized as a part of the background.

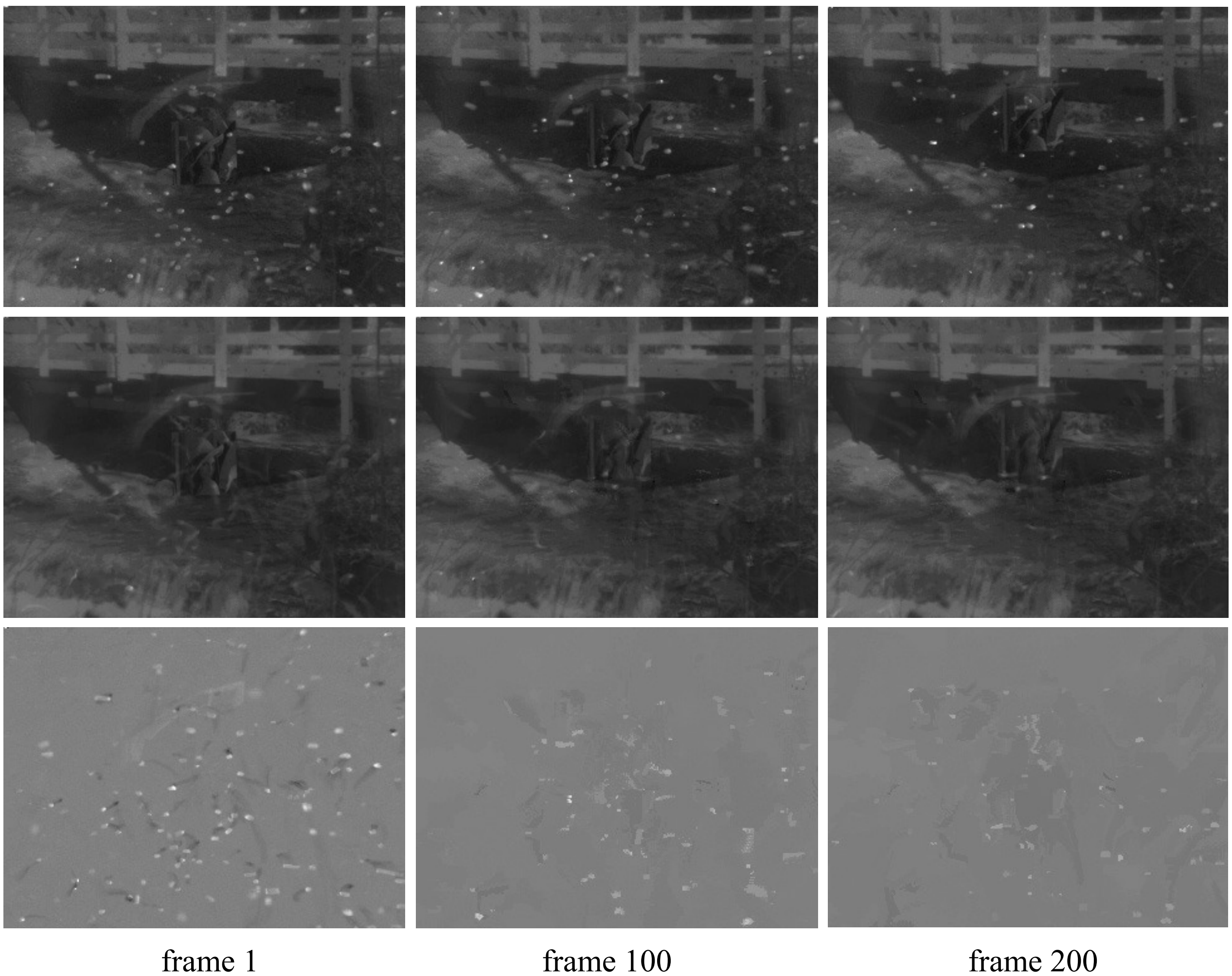

Figure 3. Experimental result: (top) input images, (middle) estimated background images, (bottom) estimated foreground images

The proposed method performs patch-based tracking. When there is suspended matter with different motions in a patch, all the suspended matter may not be tracked. Therefore, we tried to remove the suspended matter that was not tracked by applying the proposed method to the estimated background video images, which are obtained by applying the proposed method to the input video images. Figure 4 shows the result of repeatedly applying the proposed method. For comparison, we also show the result of repeatedly applying Kalman filter only, without performing tracking. From the result, we can see that the suspended matter that could not be removed with one iteration was removed by repeating the processing. Even in the case only Kalman filter was applied, the suspended matter was removed to some extent, but more suspended matter was removed and clearer background images are obtained by using tracking.

1 iteration 2 iterations

Figure 4. The result of repeatedly applying: (upper) the proposed method, (lower) Kalman filter only

4. CONCLUSION

In this study, we proposed a method that tracks the motion of suspended matter in the underwater video images and that separates the images into the foreground, which is moving fast, and the background, which is changing slowly. The result of the experiment using simulated images showed that the background images were successfully estimated. Future work includes extraction of optimal parameters and applying the proposed method to the real seabed images.

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