High-speed Object Tracking Based on Temporally Evaluated Optical Flow

Nobuhiro Kondoh Ryuzo Okada Junji Oaki Daisuke Yamamoto Hiroshi Miyazaki
Kouki Uesugi Jiro Amemiya Kenji Shirakawa Atsushi Kunimatsu

We demonstrate an active camera system for high-speed object tracking using a high-speed camera that can take an image sequence at a rate of 1000 frame/s. By making effective use of properties of high-frame-rate image sequences, our tracking algorithm enables us to robustly track a fast moving object in a typical indoor environment that contains a cluttered background under ordinary illumination, such as fluorescent lights.

In such a high frame rate, it is difficult to capture images that have a sufficient dynamic range for image processing because of a restricted exposure time of the high-frame-rate camera. Thus, strong light sources are necessary for the existing high-speed object tracking systems[1]. In order to overcome this problem, we developed a high-sensitivity high-frame-rate visual sensor system.

Figure 1 shows a typical tracking result of a fast moving object. The target is moving so fast that the target is blurred in the video-rate images and is not clearly seen. In contrast, the target is clearly seen in the high-frame-rate images. Our system is, thus, capable of distinguishing the target from the cluttered background based on our tracking algorithm, and successfully tracks the target.

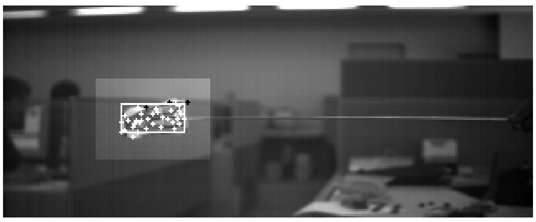
In the following sections, we describe our demonstration system, the real-time object tracking algorithm, and the high-sensitivity high-frame rate sensor system.

System Overview

Our system consists of a "camera platform" mounting a "high-speed image sensor board" and a "video camera" and a "PC for image processing" and a "PC for motor control" (see Figure 2). The "high-speed image sensor board" captures a low-sensitivity image at a rate of 1000 [fps]. The low-sensitivity image is enhanced by the "image capture/processing board" in the "PC for image processing" to be a high-sensitivity image based on the method described later. In order to realize image processing at a rate of 1000 [fps], a dual-CPU PC is used for the "PC for image processing." A process which reads the high-sensitivity images from the "image capture/processing board" executes on one CPU and our tracking algorithm executes on the other one. The position and the motion of the target are sent to the "PC for motor control", which controls the angle of pan and tilt so that the target is at the center of the field of view.

Note that the "video camera" on the "camera platform" is used for providing a real-time reference view in order to compare the quality of an image sequence at a video rate with that of an image sequence at a rate of 1000 [fps].

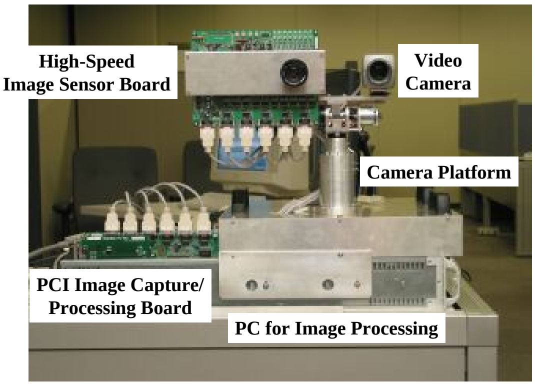
Tracking Algorithm



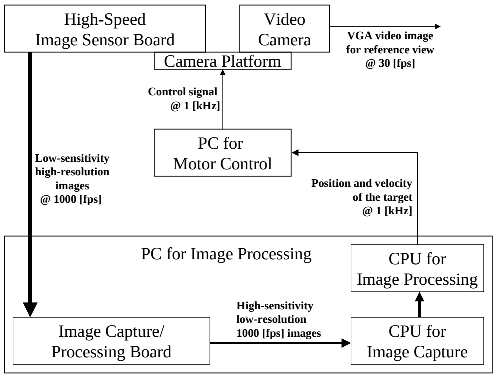
(a) High-frame-rate image with tracking result ('+' marks represent corner points being tracked. The white rectangle is a target region that circumscribes the corner points. Flicker compensation is performed in a rectangular region where brightness differs from that of other areas.)

(b) video-rate image.

Figure 1. Tracking of a fast moving object.



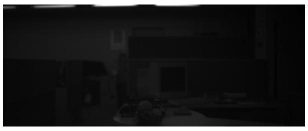
(a) Exterior of the system.



(b) Block diagram.

Figure 2. Our high-speed object tracking system.

(a) Enhanced image.



(b) Original image.

Figure 3. Enhanced image

In order to distinguish a target object from a cluttered background, motion information, which is optical flow, is useful. Motions in a high-frame-rate image sequence are much smaller than those in a video-rate image sequence. By making effective use of this property, we estimate robust optical flow in a high-frame-rate image sequence, which we call "temporally evaluated optical flow", or simply "T-Flow" [2]. We present a robust tracking method based on T-Flow. First, the fluctuation of image intensities caused by the flicker of the fluorescent lights is eliminated. Next, assuming that there are a lot of feature (corner) points on the surface of the target object, feature points are detected in the target region, and T-Flow is extracted for the feature points. Then, motion and position of the target object are estimated based on the optical flow information. Finally, useless feature points are removed and the target region is updated.

Initial target region is determined to be a moving object first coming into the field of view assuming that the camera platform is initially stationary and that there are no moving objects in the field of view.

High-sensitivity high-frame-rate visual sensor system

In order to improve the sensitivity of the high-frame-rate sensor, we increase an exposure area by making a pseudo pixel whose area is enlarged by adding the image intensities of adjacent pixels. Furthermore, adding the image intensities reduces a spatially independent noise on the original image intensities. We compute the sum of image intensities of adjacent 4x4 pixels. The resolution of an enhanced image obtained by our system is 320x128 pixels because the resolution of an original image captured by the CMOS image sensor [3] is 1280x512 pixels at 1000 [fps].

Images obtained by this improvement procedure are shown in Figure 3. Although these images are captured in an office under ordinary fluorescent lights at night, the dynamic range is improved and the interior in the office is clearly seen. In contrast, the dynamic range of an original image is insufficient for recognizing the interior.

References

[1] I. Ishii, Y. Nakabo, and M. Ishikawa, "Target Tracking Algorithm for 1ms Visual Feedback System Using Massively Parallel Processing," *Proc. of ICRA*, pp. 2309-2314, 1996.

[2] R. Okada, A. Maki, Y. Taniguchi, and K. Onoguchi, "Temporally Evaluated Optical Flow: Study on Accuracy," *Proc of ICPR*, 2002.

[3] Micron Technology, Inc. `http://www.micron .com/imaging/Products/MI-MV13.html`