Event-Driven Particle Filter for Tracking Irregularly Moving Objects

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Abstract

Conventional object tracking techniques that use general-purpose cameras and particle filters find it difficult to track irregularly and rapidly moving objects. To track an irregularly moving object without losing sight, quickly measuring the position of the object is necessary. In this study, we used a fast-response event-based camera, which is a bioinspired camera that produces a spiking output. We propose an event-driven particle filter that performs processing in response to the input from an event-based camera. Our proposed method was evaluated by presenting an event-based camera with a rectangular motion pattern that combines periodic and constant-velocity motions at various speeds. The experimental results demonstrated that our proposed method could track objects in a test video.

Keywords: Particle filter, Event-based camera, Robot vision

1. Introduction

Visual servo technology is a key technology for controlling a robot by visually detecting changes in the state of a manipulated object. A visual servo requires short sampling intervals of visual information to accurately identify the dynamics of the physical system of the target and track objects. For example, to achieve a pan–tilt system that constantly captures flying objects in its field of view or technology that allows a manipulator to serve spaghetti non-stop on a plate, visually capturing the movement of the object and applying it to the control of the robot is necessary. There is always a delay between the acquisition of visual information and the command of the robot. Therefore, estimating the post-motion state of the target as accurately as possible based on the constraints of the target's physical system is also necessary.

When capturing motion information from the outside world, problems with motion blur are unavoidable with general-purpose cameras having exposure processes. Therefore, event-based cameras [1], which outputs only pixel-by-pixel luminance change information, has attracted attention owing to its high temporal resolution and low-latency response properties. In recent years, considerable research has been performed on computer vision technology using event-based cameras [2].

In this study, we also focused on particle filters, as they can stably predict states using a large number of particles for object tracking. Generally, in image-based object tracking, particle filter calculation cycles are performed in a frame-by-frame manner.

Herein, we propose a new event-driven particle filter that performs an operational cycle for each event.

Next, a method for tracking objects in pulsating motion is proposed by integrating an event-driven camera operating at high speed and low latency with an event-driven particle filter. The proposed method was evaluated by presenting a camera with a test video on a display.

2. Proposed method

High-speed cameras with high temporal resolution and low latency are required to track objects that constantly change their motions. Event-based cameras are sensors that asynchronously detect changes in the brightness of light incident on each pixel and output polarity in combination with coordinates and time information. Event-based cameras are characterized by high dynamic range, low latency, low power consumption, and high temporal resolution.

However, even if a high-performance image sensor is employed, the position and orientation of the object will be different from when the image sensor starts measuring the object, owing to the data acquisition time and calculation time of the sensor. In this study, a particle filter was used as a prediction function to provide the target command value considering the sensing time delays. A particle filter is a type of time-series filter, which is a method of representing the probability distribution of a target state by a set of multiple particles. Particle filters can estimate the state of a target by repeating cycles of state update, likelihood estimation, and resampling. As the input to the particle filter in this study is a set of event data, an event-driven particle filter for this input is proposed and applied to object tracking.

Fig. 1 shows a flowchart of the event-driven particle filter. The process shown in the flowchart in Fig. 1 was performed once for each input event. First, as in a typical particle filter, the state p_{start}, that is, the position and orientation of each particle, is set to a random value at time t_0 as an initiation step. The above initiation step was performed only once at the start-up.

In this filter, given an event input, state pi of each particle determines its next state according to the state transition model M. Referring to Ref. 3, we devised a method for stable tracking against sudden changes in direction by simultaneously using two models with different properties for position estimation—a Gaussian window model and a second-order autoregressive model—to cope with the tracking of complex motions. To assign each particle to the state transition model, a second-order autoregressive model was applied to estimate the position of particles with high likelihood and good tracking and a Gaussian window model for particles with low likelihood. Only the Gaussian window model was used for the orientation estimation.

Next, the likelihood of each particle is evaluated. To determine the likelihood of a particle's position, an exponentially decaying function is defined for the distance from the pixel position where the particle is located to the pixel position where the event occurred, which is added to the current particle's weight. In other words, if an event occurs near the position of a particle, the state of the particle is judged to be likely. To evaluate the likelihood of attitude, a group of Gabor filters with a strong response to five levels of orientation from 0 ° to 90 ° was applied to the input image. The likelihood of a particle is evaluated based on the orientation image with pixel response in the highest filter image, and the particle weights are accordingly calculated.

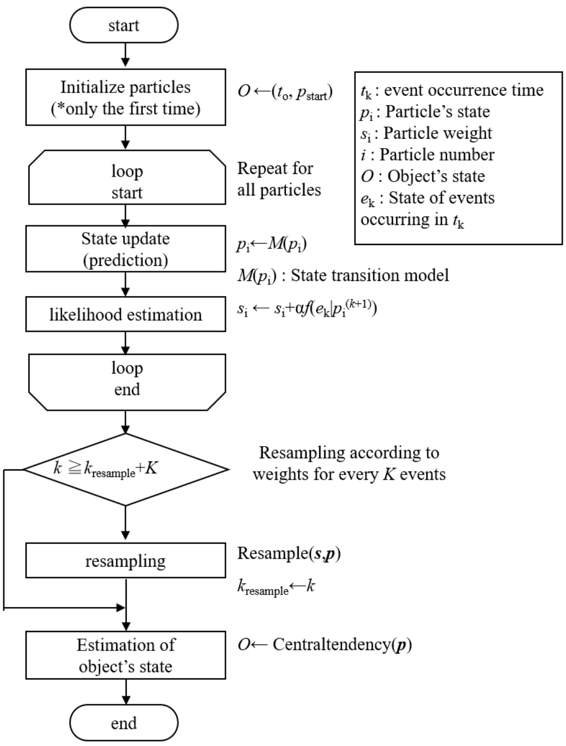

Fig. 1 Flowchart of the event-driven particle filter.

The above state and likelihood estimates were computed for all particles upon receipt of an event input. The state O of the tracked objects is the median of the state p_{start} of all particles.

Finally, at the stage where K event inputs are received, a particle resampling process is performed. In the resampling process, systematic sampling is performed depending on the weight of each particle, with particles with higher weights generating more replicas, and particles with lower weights being deleted. By repeating this operation, event-driven particle filtering can be achieved.

3. Experiments and Results

The proposed algorithm was evaluated in the experimental environment shown in Fig. 2. As the tracking target, a video of a rectangular object with a combination of constant angular velocity and periodic motion along a circular orbit was shown on a 360-Hz display, which was presented to an event-based camera, SilkyEvCam (CenturyArks Co., Ltd). The image resolution of the camera was VGA (640 × 480 pixels). A video was created at 120 °/s as a constant velocity motion, 4-Hz period as a periodic motion, and 30 ° as amplitude. A particle filter was applied to the results of the noise filtering performed on the event information acquired by the camera.

Figs. 3 and 4 show the output results of applying the proposed method every 1 ms in an offline setting. Fig. 3 shows the state of each particle (blue circle in the figure) and the estimated position of the object (red circle in the figure) for the image obtained by integrating the events between 200 and 1 ms at the start of the measurements. The direction of the arrow at the center of each particle and object represents the orientation, and the size of the circle indicates the magnitude of the weight. Fig. 4 shows the transition of the position of the object in the image coordinate system. The distance from the origin (radial direction) is constant, and the circumferential direction shows a tendency of back-and-forth motion characteristics, which is a combination of constant-velocity angular motion and periodic motion. Fig. 3 shows that the particles are distributed such that they cover the object, and the object is well tracked in terms of its probability distribution.

We also confirmed that these operations can be performed within a computation period of 10 ms in the

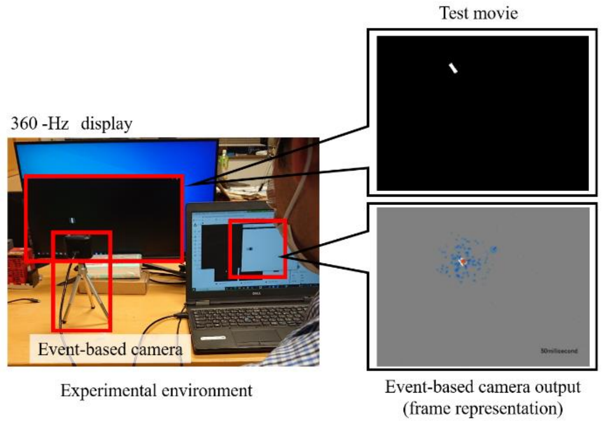

Fig. 2 Experimental environment.

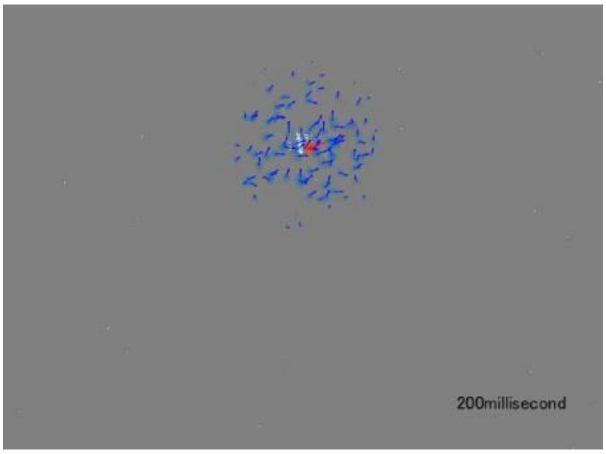

Fig. 3 State of each particle and estimated position and pose of the target at 200 ms.

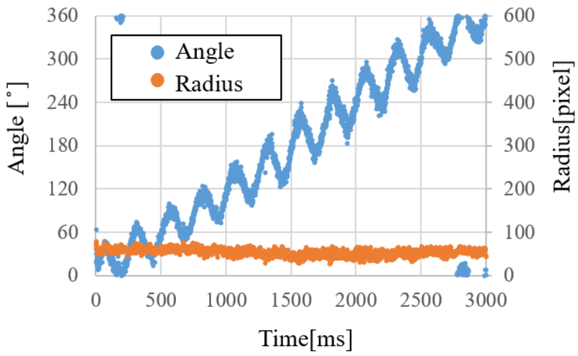

Fig. 4 Changes in target position and orientation predicted by the proposed method.

online mode. As a breakdown of the processing time, noise filtering takes 50 µs, and azimuth selectivity filtering takes 5 ms and the event-driven particle filtering required 100 µs/event for processing a single event, indicating that the azimuth selectivity filter is a bottleneck of the operation. It is apparent that there is an arithmetic bottleneck in the azimuth selectivity filter.

4. Conclusion

In this paper, we proposed an object tracking method using an event-driven particle filter. By presenting a test movie to a camera with a rectangular object to be tracked that combines constant velocity and periodic motion, we demonstrated that the proposed method can track an object offline with a 1-ms period.

The next step is to improve the processing efficiency by making the orientation selectivity filtering process event-driven and to improve the accuracy of the position and orientation estimation.

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References

1. C. Posch, D. Matolin, and R. Wohlgenannt, "A QVGA 143 dB dynamic range frame-free PWM image sensor with lossless pixel-level video compression and time-domain CDS", IEEE Journal of Solid-State Circuits, Vol. 46, No. 1, pp. 259-275, 2010.
2. G. Gallego et al., "Event-based vision: A survey", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 44, No. 1, pp. 154-180, 2020.
3. Y. Shiina, & T. Ikenaga, "Dual model particle filter for irregular moving object tracking in sports scenes", In: APSIPA Annual Summit and Conference (ASC 2011), 2011.

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