

Thesis Abstract

In recent years, motion detection and analysis in computer vision draws an increasing attention in a wide range of applications including high speed surveillance, traffic enforcement, automotive crash safety, and navigation of autonomous vehicles, etc. These applications require continuous image acquisition and real-time processing techniques, including optical flow, image segmentation, object recognition and object tracking, etc. Traditionally, optical flow and object tracking are computed on a series of consecutive image frames captured by standard cameras. Such imaging systems employ charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) active pixel sensors (APS) and capture images at a certain frame rate. To detect high speed motion activities, the sensors need to run at a very high frame rate, i.e. more than 500 frames/second. Massive quantities of raw, redundant image data must be transmitted and processed before the features of interest are obtained. These data exerts heavy pressure on the transmission bandwidth and the following processing stage, thus, such frame-based data acquisition and processing systems are difficult to satisfy real-time requirement. Moreover, capturing fast motions using standard cameras leads to motion blur and lose of the motion trajectory during the blind time between two consecutive frames, which restrict the accuracy of object tracking. The tracking accuracy issue can be alleviated by using high-speed cameras, however, it introduces much more redundant data and tremendous computational cost.

The development of dynamic vision sensors (DVSs) has provided a solution to the above-mentioned issues. Unlike frame-based imagers, DVSs have no concept of ‘frame’ but output asynchronous pixel events. Each pixel continuously detects and logarithmically responds to the illumination changes. A pixel is triggered to output an event only when its detected illumination change goes beyond the defined threshold. Such mechanism enables DVSs to reduce data redundancy by filtering out the redundant data from static background. Considering that illumination variation is related to actual movement in most common

scenarios, the DVSs are capable of extracting motion related information directly. Several event-based algorithms for object tracking and optical flow have been developed taking advantage of the spatial-temporal characteristics of binary events. It has been proven that the employment of DVS in object tracking and optical flow can reduce the computational cost significantly. However, the accuracy of the event-based algorithms is restricted due to the lack of absolute light intensity of DVS events. Moreover, the pixels in a traditional DVS work individually, resulting in high sparseness of pixel events and poor accuracy in flow estimation with respect to fast moving objects.

This thesis presents the developments of two smart event-based motion sensors with feature extraction, such that the designed motion sensors can be used to develop more algorithms in the field of motion detection and analysis. In addition, an event-driven tracking algorithm tailored for the designed motion sensor is also proposed. With the novel designed motion sensors and proposed algorithm, the event-based optical flow and object tracking algorithms can achieve much higher accuracy compared to those using traditional DVSs while maintaining real-time performance. The main contributions of this thesis are summarized in the following four aspects: (1) The recently developed event-based DVSs are exhaustively investigated. Compared with standard cameras, event imagers have high temporal resolution and low latency, both in the order of micro-seconds, and a large dynamic range. Furthermore, event-driven signal processing algorithms in the context of object tracking and optical flow are reviewed, showing possibilities in real-time applications. (2) The first hybrid motion sensor that can generate both frames and asynchronous events with intensity (named grayscale events) is designed and implemented. The designed hybrid sensor has independent pixels that report asynchronous events, including pixel locations, with their corresponding illumination. It significantly reduces redundant data from static background and extract essential information for motion analysis. In contrast to existing event cameras with intensity readout (DAVIS and ATIS cameras), the designed sensor is free of exposure time, contributing to fast-response imaging of high speed objects. In addition, pixels in this hybrid sensor are globally controlled to capture full frames on demand, thus benefits the environmental perceptions

in computer vision tasks. Accordingly, a 384×320 -pixel prototype sensor was designed and fabricated. (3) An event-guided discriminative tracking method tailored for the designed hybrid motion sensor is proposed for detection and tracking of high speed moving objects. The proposed tracking algorithm incorporates a traditional frame-based tracking-by-detection algorithm with two event-guiding methods. Compared to the classical trackers, the proposed tracking algorithm exploits an online adaptive searching area to achieve a more accurate localization. Moreover, the gray-level intensity of event packages generated by the designed hybrid motion sensor is utilized to reconstruct supplement samples and update the tracker model over time. The experimental results indicate that the proposed algorithm presents high computational efficiency and outperforms the state-of-the-art trackers in terms of accuracy and real-time performance. (4) A novel motion sensor with pixel rendering mechanism is designed and implemented for optical flow estimation. Besides detection of illumination changes, pixels in the proposed motion sensor are interconnected and communicate event status among each other through a pixel rendering module (PRM). Each active pixel together with its four-neighbor pixels report grayscale events to provide sufficient data in gradient extraction which is essential in flow estimation. Thus, the proposed sensor fundamentally solves the accuracy problems of existing event-driven optical flow estimation, which are caused by event sparseness and lack of event intensity. A 64×64 prototype was fabricated in 0.35um 2P4M Opto process. Experiments were conducted on both synthesized data based on Middlebury and MPI database and real data collected from the designed sensor, showing an improvement (by 17%) in accuracy performance of event-flow estimation.