Event Camera-based Visual Perception

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Frame-based cameras are often used as one of the core sensors by AI-based autonomous systems in self-driving cars, unmanned aerial vehicles (UAV), and robotic applications. However, these cameras have their limitations due to the nature of frame-based sensors and may lead to difficulties in visual sensing in autonomous systems. To overcome the limitations of frame-based sensors, Professor Yoon's research group used an advanced visual sensor called event cameras, also known as neuromorphic cameras, to develop novel visual sensing technology that works even under challenging and extreme circumstances. In 2021, the research group has presented several works in top-tier AI journals, such as IEEE TPAMI and IJCV, and also in various top-tier AI conferences, such as IEEE/CVF CVPR and ICCV. Moreover, the research group has won first place in both tracks of the 2021 CVPRW DSEC competition hosted during the CVPR 2021 conference, and their work has been featured in both the IEEE SPECTRUM and VISION SYSTEMS DESIGN magazines as novel technology to keep an eye on. The event-camera based technology developed in this research will ultimately enhance visual sensing technology and lead to impactful changes for industrial applications.

1. Background (objectives)

Visual information plays a significant role in AI-based autonomous systems as they use various visual sensors to perceive the surrounding environment. Among visual sensors, frame-based cameras have become one of the most conventional sensors as they provide a plethora of cognitive information. However, frame-based cameras are vulnerable to extreme lighting conditions due to their low dynamic range. Frame-based cameras also suffer from motion blur with its low frame rate when the camera or subject is in dynamic motion. As such, it is necessary to use a new visual sensor and to develop visual perception technologies optimized for a more diverse and severe environment.

2. Contents

In this study, visual perception technologies using event cameras were developed to overcome the limitations of frame-based cameras. The event camera is a neuromorphic camera designed to mimic the human visual systems. Unlike conventional frame-based cameras, event cameras capture individual pixels with brightness changes and record them in the form of asynchronous event streams. Because of these characteristics, event cameras have a very short image acquisition time (~10us) and have more than double the dynamic range compared to conventional frame-based cameras. The event camera also operates robustly under extreme illumination environments.
However, since event streams have a different data format than conventional frame-based images, directly applying existing frame-based visual perception technologies is a challenge. At first, technologies for generating high-dynamic-range (HDR) images and super-resolution from event streams (IJCV, TPAMI) were developed. The event streams were used to acquire frame-based images even under both low and high illuminance; the image retains all the advantages of an event camera whjle being compatible with frame-based visual perception tasks. Furthermore, the highest performance in image classification and semantic segmentation (CVPR paper) was achieved by utilizing only event streams, showing that event data can be used directly without having to generate frame-based images from event data.

The event streams suffer from sparsity because events exist only for pixels where there is a change in brightness. To mitigate the sparsity issue, an event-image recycling framework (ICCV paper) was developed to use both frame-based images and event streams to selectively extract optimal features given certain conditions. Where there is no event, the framework mainly extracts features from frame images, while when there are severe brightness changes and motion blur, the framework emphasizes the features from event streams. Moreover, a wide field-of-view (WFoV) event camera system based on a fisheye lens was built; this system helps to reduce sparsity of event streams by using the omnidirectional visual information to provide more abundant features. Using these features, the research team developed 3D depth estimation algorithm (RA-L paper), which was featured in IEEE SPECTRUM and VISION SYSTEMS DESIGN. Lastly, the research team won first place in both the Event-Only and Event-Image tracks at the DSEC Challenge, which is a 3D depth estimation competition for event camera-based autonomous driving held at the 2021 CVPR Workshop.

3. Expected effect

In this study, event camera-based perception technologies were developed to overcome the limitations of existing frame-based cameras. From an academic perspective, the visual perception technologies obtained from this study are pioneering research for novel vision sensors and are expected to lead numerous follow-up studies as well as create new research fields. In a technological and industrial point of view, the results of this study are highly versatile as they can be used for various mobility applications (autonomous vehicles, drones, robots, UAVs) as well as intelligent monitoring and imaging systems. In addition, event cameras have shown capability of replacing or complementing existing frame-based cameras. Lastly, this study is expected to be used in various fields such as autonomous driving systems and smart cities leading to great economic benefits.

Figure 1. Certification of the CVPRW2021 DSEC Event-only (Left) and Event-Image (right) track 1st place

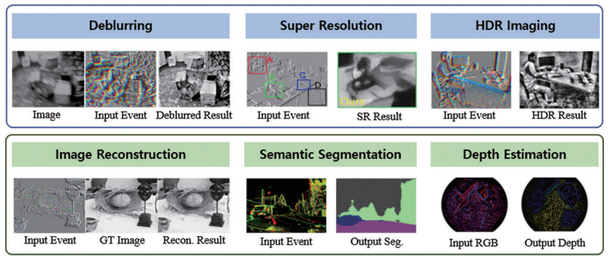

Figure 2. Event Camera-Based Visual Cognitive Technology Study Summary

Research outcomes

Paper

"Joint Framework for Intensity Image Reconstruction, Restoration, and Super-Resolution with an Event Camera," IEEE T. PAMI, 2021.
`E2SRI: Learning to Super-Resolve Intensity Images from Events," IEEE T. PAMI, 2021.
"Learning to Reconstruct HDR Images from Events, with Applications to Depth and Flow," International Journal of Computer Vision (IJCV), 2021.
`EOMVS : Event-based Omnidirectional Multi-View Stereo," IEEE Robotics and Automation Letters (RA-L), 2021.
``EvDistill: Asynchronous Events to End-task Learning via Bidirectional Reconstruction-guided Cross-modal Knowledge Distillation," IEEE/CVF Conf. CVPR, 2021.
"Dual Transfer Learning for Event-based End-task Prediction via Pluggable Image Translation," IEEE/CVF ICCV, 2021.
"Event-Intensity Stereo: Estimating Depth by the Best of Both Worlds," IEEE/CVF ICCV, 2021.

Award

1st Place in CVPRW 2021 DSEC Competition (Event-only Track)
1st Place in CV.2PRW 2021 DSEC Competition (Event-Image Track)

Press release

IEEE SPECTRUM (https://spectrum.ieee.org/new-camera-sees-more)
VISION SYSTEMS DESIGN(https://www.vision-systems.com/non-factory/article/14212132/multiview-stereo-method-uses-eventbased-omnidirectional-imaging)

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