High Speed Event Based Camera Modeling for Fluid Flow Synthetic Image Processing

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Fluid modeling for hypersonic applications is currently a field of great interest, though these models are currently limited without empirical data to verify the models on. Typical high-speed wind tunnels often impart geometric constraints along with harsh flow environments, making observation of the flow difficult. To improve models, high resolution and high frame rate imaging systems are required in order to capture the behavior of the flow. With higher resolution and frame rates, there is a requisite increase in data throughput, which further exacerbates the geometric constraints present in most wind tunnels. To decrease required data throughput, various methods of data compression have been proposed: multi-level processing to determine pixel relevancy [1], in pixel analog-to-digital conversion [2], and even removal of redundant pixels through a bio-inspired solution, typically known as event-based camera operation.

Event cameras differ from conventional cameras in that each pixel is read out asynchronously, depending on whether there have been any changes in light detected in the pixel. Due to this, only new image data is transmitted from the sensor, dropping redundant pixels that have not changed in the observed scene. The primary benefit to asynchronous sampling for event cameras is that for scenes that have primarily still scenery with motion in the foreground, the area of motion is sampled at a much higher rate than the still background. For high speeds characterizing supersonic and hypersonic flows, this focus on motion is paramount.

Due to the difficulty of integrating a new camera system, this work utilized a simulation-based approach to determine the efficacy of event cameras for high-speed fluid flows. Synthetic images were generated at varying particle densities to simulate a particle image velocimetry (PIV) experiment, and a model of an event camera was created to process these generated images. The highest particle density trial can intuitively be seen to be the trial that would create the most events. As each particle moves through the simulated scene, it generates events, so more particles entail more events for a given flow field.

With the highest density trial, on average, only 30% of pixels between generated images showed change in lighting significant enough to warrant registering an event, indicating that the majority of data collected by a standard frame camera for the same scene would be redundant from frame to frame.

With these benefits come certain restrictions. First, particles used for PIV measurements need to be carefully selected so that they reflect enough light to trigger an event in a real event camera system. Second, high speed PIV applications rely on pulsed light sources to help mitigate motion blur, though pulsed light sources may generate false events in a real event camera system. Both limitations must be weighed carefully before implementation, which is not an insurmountable situation.

Event cameras are continually evolving and becoming more effective at sampling scenes with high motion content and pose a serious opportunity for more effective fluid flow measurements, particularly showing promise for PIV experiments. Other fluid flow experiments, such as oil flow visualization and pressure sensitive paint methods, may also experience benefits from event cameras. Simulations can be conducted for these types of experiments in future work, leveraging the results of the efforts of this project.

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Statement of Research Advisor

This undergraduate research project that Mr. Rush has undertaken, regarding creating new methods to tackle the big data problem for large camera arrays, is very timely, important, and relevant to ongoing interdisciplinary projects between my group in ECE and Dr. Thurow's group in AE.

- Michael C. Hamilton, Electrical and Computer Engineering

References

[1] Pantho, M. J. H., Bhowmik, P., Bobda, C., "Pixel-Parallel Architecture for Neuromorphic Smart Image Sensor with Visual Attention," *Proc. of IEEE Computer Society Annual Symposium on VLSI*, pp. 245-250. (2018).

[2] Tyrell, B., et al., "Time Delay Integration and In-Pixel Spatiotemporal Filtering Using a Nanoscale Digital CMOS Focal Plane Readout," IEEE Transactions on Electron Devices, 56(11), pp. 2561-2523,(2009).

Authors Biography

Nick is a senior majoring in electrical and aerospace engineering at Auburn University. He performs research with the Auburn Nanosystems Group over various topics including nano-films, cryogenics, and imaging system hardware design. He was chapter president of Sigma Gamma Tau at Auburn University, and has previously interned with Uhnder Inc., where he worked on RTL automation scripts. He is currently interning with The MITRE Corporation, working on anti-tamper digital hardware designs.

Dr. Michael C. Hamilton received the B.S.E.E. degree from Auburn University in 2000, and the M.S.E.E. and Ph.D. degrees in electrical engineering from The University of Michigan, in 2003 and 2005, respectively. From 2006 to 2010, he was a member of Technical Staff at MIT-Lincoln Laboratory. In 2010 he joined the Electrical and Computer Engineering Department at Auburn University, where he is now a James B. Davis Professor. In addition to his research group (Auburn Nanosystems Group) at Auburn University, he is the Director of the Alabama Micro/Nano Science and Technology Center (AMNSTC). In 2022, he joined the Google Quantum AI team as a Visiting Faculty Researcher. His research interests include superconducting electronics technologies, microwave superconductivity and packaging/integration technologies for extreme environments (including cryogenic and quantum systems). He has served as the Auburn University IEEE Student Chapter Faculty Advisor, is Chair of MTT-7 Technical Committee on Microwave Superconductivity and Quantum Technologies, and is an IEEE JMW Topic Editor in the MTT-7 area.

Dr. Brian Thurow is the Department Chair and W. Allen and Martha Reed Professor in the Department of Aerospace Engineering at Auburn University. He received his B.S. (1999), M.S. (2001) and Ph.D. (2005) from The Ohio State University and established the Advanced Flow Diagnostics Laboratory at Auburn University in 2005. Dr. Thurow has taught classes in aerodynamics, propulsion, light-field imaging, optical diagnostics, compressible fluid dynamics and turbulence. His research program is focused on the development and application of advanced image-based diagnostics for aerothermal measurements with a focus on multi-spectral and 3D imaging techniques using plenoptic cameras or multi-camera arrays. His research has been sponsored by the Army Research Office (ARO) and Air Force Office of Scientific Research (AFOSR), both of which started with Young Investigator Program grants, as well as the Office of Naval Research (ONR), Air Force Research Laboratory (AFRL), National Science Foundation (NSF), NASA Langley Research Center, Sandia National Laboratories and several DOD SBIR/STTR awards. Dr. Thurow has received numerous awards including an NDSEG Graduate Research Fellowship; the SGA Outstanding Faculty Member Award in 2006, 2008, 2009, 2012 and 2013; the AIAA Most Outstanding Faculty Member Award in 2009, 2012 and 2013; the William F. Walker Teaching Award for Excellence in 2009; the Auburn Alumni Engineering Council Research Award for Excellence in 2009; the Provost's Award for Supporting Graduate Scholarship in 2011 and the 2015 Konrad Dannenberg Educator of the Year Award.