New camera offers ultrafast imaging at a fraction of the normal cost

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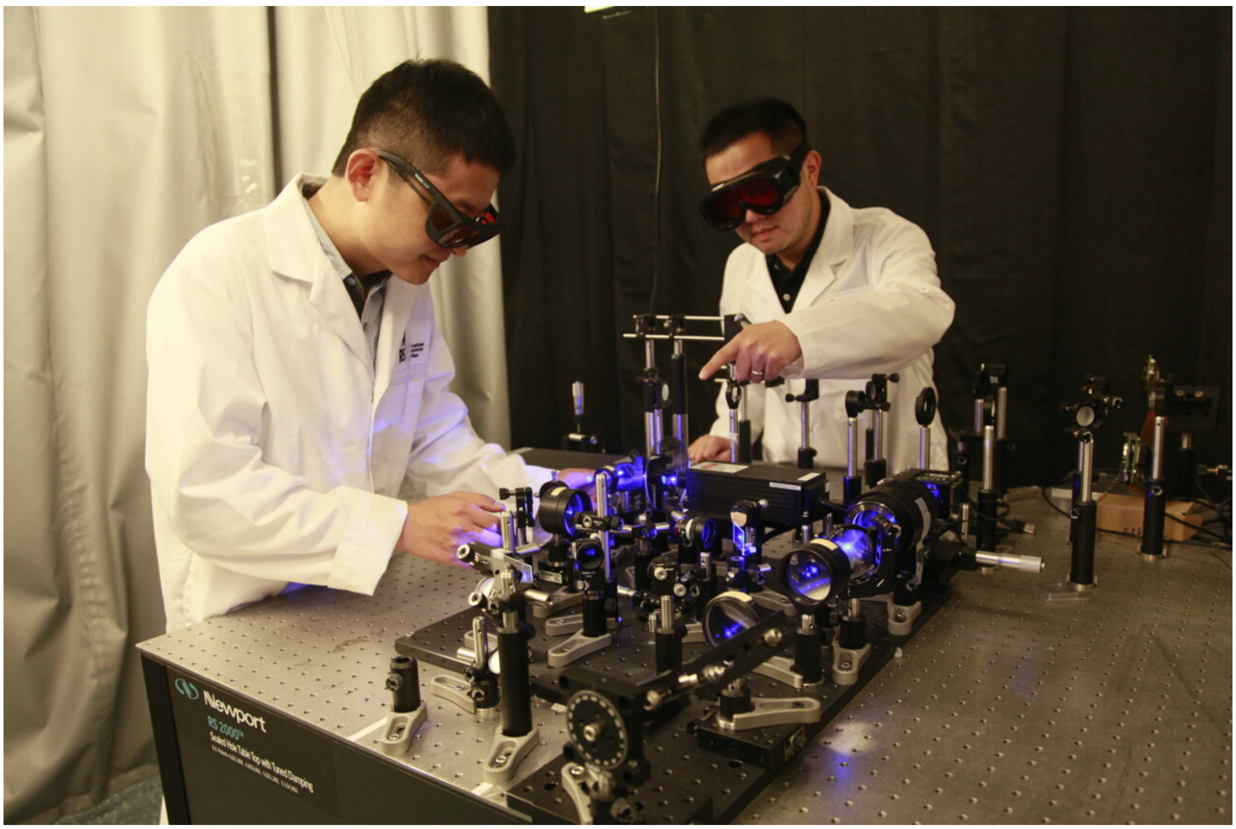

Researchers developed a diffraction-gated real-time ultrahigh-speed mapping (DRUM) camera that can capture a dynamic event in a single exposure at 4.8 million frames per second. Pictured are researchers Xianglei Liu and Jinyang Liang working on the optical setup. Credit: Xianglei Liu and Jinyang Liang, Institut national de la recherche scientifique (INRS)

Capturing blur-free images of fast movements like falling water droplets or molecular interactions requires expensive ultrafast cameras that acquire millions of images per second. In a new paper, researchers report a camera that could offer a much less expensive way to achieve ultrafast imaging for a wide range of applications such as real-time monitoring of drug delivery or high-speed lidar systems for autonomous driving.

"Our camera uses a completely new method to achieve high-speed imaging," said Jinyang Liang from the Institut national de la recherche scientifique (INRS) in Canada. "It has an imaging speed and spatial resolution similar to commercial high-speed cameras but uses off-the-shelf components that would likely cost less than a tenth of today's ultrafast cameras, which can start at close to $100,000."

In a paper, titled "Diffraction-gated real-time ultrahigh-speed mapping photography" appearing in *Optica*, Liang together with collaborators from Concordia University in Canada and Meta Platforms Inc. show that their new diffraction-gated real-time ultrahigh-speed mapping (DRUM) camera can capture a dynamic event in a single exposure at 4.8 million frames per second. They demonstrate this capability by imaging the fast dynamics of femtosecond laser pulses interacting with liquid and laser ablation in biological samples.

"In the long term, I believe that DRUM photography will contribute to advances in biomedicine and automation-enabling technologies such as lidar, where faster imaging would allow more accurate sensing of hazards," said Liang. "However, the paradigm of DRUM photography is quite generic. In theory, it can be used with any CCD and CMOS cameras without degrading their other advantages such as high sensitivity."

Creating a better ultrafast camera

Despite a great deal of progress in ultrafast imaging, today's methods are still expensive and complex to implement. Their performance is also limited by trade-offs between the number of frames captured in each movie and light throughput or temporal resolution. To overcome these issues, the researchers developed a new time-gating method known as time-varying optical diffraction.

Cameras use gates to control when light hits the sensor. For example, the shutter in a traditional camera is a type of gate that opens and closes once. In time-gating, the gate is opened and closed in quick succession a certain number of times before the sensor reads out the image. This captures a short high-speed movie of a scene.

By considering the space-time duality of light, Liang figured out how to accomplish time gating using light diffraction. He realized that rapidly changing the tilt angle of periodic facets on a diffraction grating, which can generate several replicas of the incident light traveling in different directions, could present a way to sweep through different spatial positions to gate out frames at different time points.

These frames could then be put together to form an ultrafast movie. Turning this idea into a working camera required a multidisciplinary team that brought together expertise in areas such as physical optics, ultrahigh-speed imaging and MEMS design.

"Luckily, it is possible to accomplish this type of swept diffraction gate by using a digital micromirror device (DMD)—a common optical component in projectors—in an unconventional way," said Liang. "DMDs are mass-produced and require no mechanical movement to produce the diffraction gate, making the system cost-efficient and stable."

Capturing fast dynamics

The team created a DRUM camera with a sequence depth of seven frames, meaning that it captures seven frames in each short movie. After characterizing the system's spatial and temporal resolutions, the researchers used it to record laser interactions with distilled water.

The resulting time-lapse images showed the evolution of a plasma channel and the development of a bubble in response to a pulsed laser, with the measured bubble radii matching those predicted by cavitation theory. They also imaged the bubble dynamics of a carbonated drink and captured transient interactions between an ultrashort laser pulse and a single-layer onion cell sample.

"DRUM photography may even be applied to nano-surgeries and laser-based cleaning applications," said the paper's first author Xianglei Liu, formerly of INRS and now at Ansys.

The researchers are continuing to work on improving the performance of DRUM photography, including upping the imaging speed and sequence depth. They also want to explore capturing color information and applying the system to additional applications such as lidar.

More information: Jinyang Liang et al, Diffraction-gated real-time ultrahigh-speed mapping photography, *Optica* (2023). DOI: 10.1364/OPTICA.495041

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