

Why a Steady Image Can Be the Blurrier One

Watch the gaps as well as the mark



A broad mark is easy to track; narrow grille gaps test whether fine detail survives.

A painted mark on a ventilation housing is easy to follow in a video. The narrow gaps between the grille slats ask a harder question. Can the camera preserve that detail while it moves? A sequence in which the mark hardly changes position may still show indistinct gaps. Another sequence may shake visibly while preserving sharp gaps in every frame.

The distinction comes from what happens during an exposure. A pixel collects light over an interval. If camera direction changes during that interval, a stationary feature contributes light at several image positions. The resulting image has both an average feature position and motion spread around that position. These describe different aspects of the recorded detail. [Exposure model in Gu and colleagues](#).

Moving whole frames afterwards can make the sequence easier to watch. Repositioning alone does not undo the mixing that

occurred inside each exposure. Deblurring is a separate reconstruction problem. Stanford researchers demonstrated this distinction when low-light motion blur remained visible in video after stabilisation. [Stanford technical report](#).

The viewing angle puts the motion into image units. In a calculated camera example with a 2° horizontal field across 1,920 pixels, one pixel covers about 18.2 microradians near the centre. A microradian is one millionth of a radian. Narrowing the field with the same pixel count makes a given angular movement span more pixels.

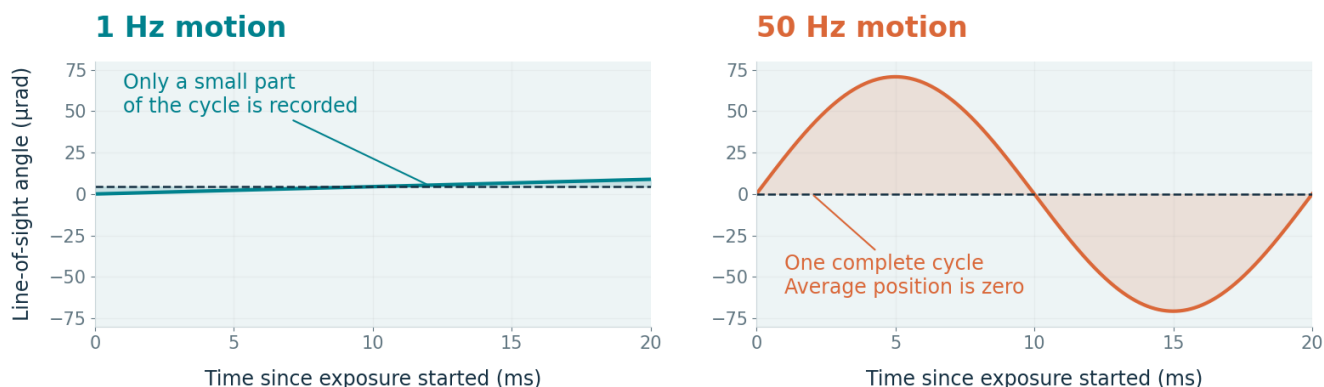
That conversion is useful, but it does not establish a universal acceptable blur. The width and contrast of the feature, focus and the inspection task also matter. First separate movement of the feature's average position from spreading of its detail.

A steady feature position can coexist with lost fine detail.

Two motions with the same headline number

Same angular RMS. Different motion during exposure.

Both sinusoids have 50 μrad RMS over a complete cycle; each window below is 20 ms.



Dashed line: average position during the exposure. Shaded area: departure from that average.

These two windows start at a zero crossing. Other start phases change the slow-motion result.

Uniform exposure, a stationary subject and small one-axis rotation; motion is calculated.

One selected exposure phase shows why equal full-cycle RMS does not imply equal blur.

Consider two calculated camera motions about one axis. Both are smooth sine waves with an angular root-mean-square value of 50 microradians, measured over complete cycles. Root mean square, or RMS, describes the typical magnitude about their zero mean; each wave reaches approximately 70.7 microradians in either direction. One completes one cycle per second. The other completes 50.

Give both cameras a 20 millisecond exposure. Assume a stationary subject, small camera rotation and a global shutter that weights light uniformly throughout the interval. Ignore other sources of blur. These conditions isolate the effect of timing without assuming any particular product performance.

During 20 milliseconds, the slow motion completes only one fiftieth of a cycle. Most of its movement occurs outside any one exposure. The fast motion completes a full cycle inside every exposure: it goes one way, returns and goes the other way. Its average position is zero, even though the image has sampled a wide range of positions.

To make the comparison precise, calculate the average angle within each exposure. Then calculate the variance of the angle around that exposure's own average. Repeat across evenly distributed starting phases, so that no fortunate shutter timing decides the answer. Take the square root of the average variance to express the within-exposure spread in microradians.

Pointing analysis distinguishes exposure displacement, smooth smear and residual jitter. Here, within-exposure spread includes both smooth smear and faster motion around the average; it is broader than that formal definition of jitter. [Seiler and colleagues, Section 2.](#)

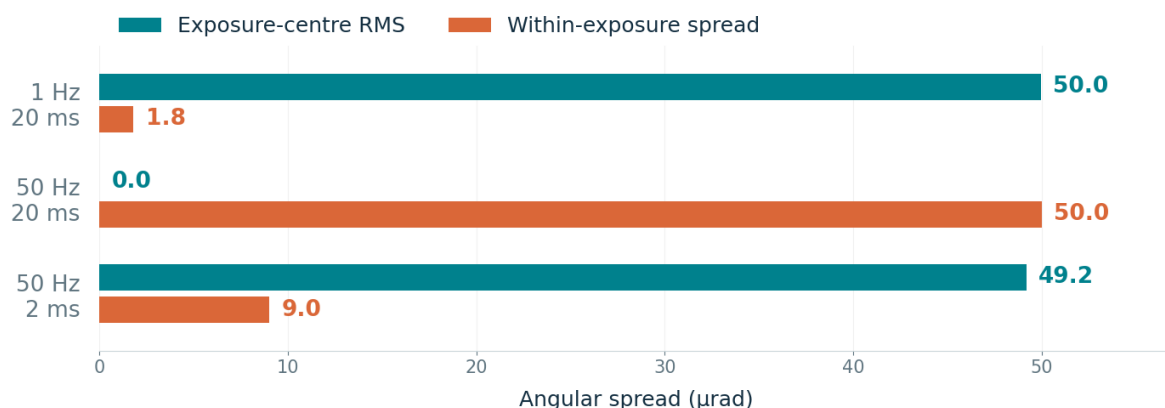
The traces show one selected starting phase. Starting elsewhere changes the slow trace, which is why the numerical comparison averages over phases.

Exposure time decides how much motion becomes position change and how much becomes spread.

A shorter exposure changes the balance

Shortening the exposure moves the balance

Calculated across uniformly distributed vibration phases • angular RMS remains 50 μrad



Exposure-centre RMS: spread of the mean positions across start phases, not the step between adjacent frames.

Within-exposure spread: square root of the phase-averaged variance about each exposure's own mean.

Their squared values sum to $50^2 \mu\text{rad}^2$. The two RMS values themselves must not be added.

Calculated exposure statistics separate average position from motion spread within each frame.

For the slow, 1 Hz motion with a 20 millisecond exposure, the calculated RMS of the exposure average positions is 50.0 microradians after rounding. Within-exposure spread is only 1.8 microradians. Across different starting phases, frames can occupy noticeably different positions while accumulating little motion inside each exposure.

For the 50 Hz motion at the same exposure, every interval covers one complete cycle. The exposure average position is always zero, but within-exposure spread is 50.0 microradians. The feature can look stationary from frame to frame while its edges are broadened. Averaging the position has hidden the oscillation from a simple frame-position measurement.

Now shorten the fast case to 2 milliseconds. Within-exposure spread falls to 9.0 microradians. The RMS of exposure average positions rises to 49.2 microradians across starting phases. The camera's physical motion is unchanged. A shorter interval records a smaller portion of each cycle,

leaving more of the motion visible as different exposure positions.

In the 2° view introduced earlier, the three within-exposure spreads correspond to approximately 0.10, 2.75 and 0.50 pixels. These are calculated RMS widths of the motion distribution, not full blur-trail lengths or guaranteed limits on resolvable detail. Different paths can have the same RMS width and distribute contrast differently.

There is also a light budget. With unchanged illumination and aperture, reducing exposure from 20 to 2 milliseconds collects one tenth as many signal photons. Where photon counting noise dominates, signal-to-noise ratio falls to about 0.32 of its former value. Other noise sources can change that relationship. [STScI signal-to-noise guidance](#).

Shorter exposure therefore exchanges one problem for another unless sufficient light is available. Increasing display brightness does not restore the missing photon information.

Less spread during an exposure does not mean the camera moved less.

Make the comparison without fooling the camera



A proposed low-light inspection setup makes illumination part of the exposure decision.

Use a stationary target with both a broad feature to track and fine edges or gaps to inspect. Keep the field of view, focus and target distance fixed. Compare several exposure durations while recording the actual frame timing. Record gain and illumination as well, because a cleaner edge with much more noise may not improve the task.

Measure two outcomes separately: the feature's average position in each frame and the preservation of its fine detail. Keep processing settings fixed and identify any frame repositioning, sharpening or noise reduction. A changing processing mode can otherwise masquerade as a mechanical improvement.

Frame timing deserves particular care. A camera recording 25 frames per second samples a 50 Hz vibration after exactly two cycles between exposure starts. If those timings remain locked, every short exposure begins at the same phase. The frame positions can stay constant even though the camera is oscillating. The phase-averaged position values in the chart are therefore not

predictions of the difference between adjacent frames at every frame rate.

A faster, independent angular recording can reveal this hidden motion. A deliberate change in frame timing may also expose it. Neither a steady sequence nor a single frame-position trace is sufficient evidence that exposure blur is small.

Finally, check the shutter. A rolling shutter exposes different rows at different times. Shortening each row's exposure can reduce its blur while leaving geometric distortion between rows. The single-interval calculation here assumes a global exposure and does not model that effect. [Rolling-shutter timing model](#).

For an Inventra S³ camera configuration, ask for image evidence with the relevant exposure, frame timing and lens setting attached. Judge whether the required detail survives each exposure as well as whether its position stays steady across the sequence.

Record exposure and frame timing, then assess position and fine detail separately.

Sources and further reading

[Original Inventra S³ article](#)

Inventra Inc. | 2026

[Method to Compute Pointing Displacement, Smear, and Jitter Covariances for Optical Payloads](#)

Authors' accepted manuscript, AIAA Journal of Guidance, Control, and Dynamics | 2026

[Coded Rolling Shutter Photography: Flexible Space-Time Sampling](#)

Columbia University; IEEE International Conference on Computational Photography | 2010

[Digital Video Stabilization and Rolling Shutter Correction using Gyroscopes](#)

Stanford University | 2011

[WFPC2 Instrument Handbook, Section 6.5: Signal-to-Noise Ratio Estimation](#)

Space Telescope Science Institute

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