Low Vibration, Noise Minimized Optical Shutter using DC Brushed Motors

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Introduction

- Optical Shutters control the duration of light exposure in various optical applications on a millisecond scale. [1]
- High Noise, vibration, and heat dissipation introduced by Mechanical Optical Shutter can disturb an optical system.

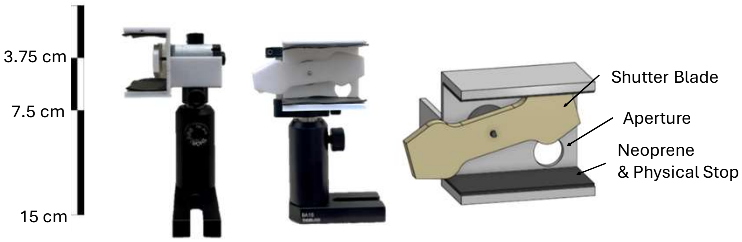
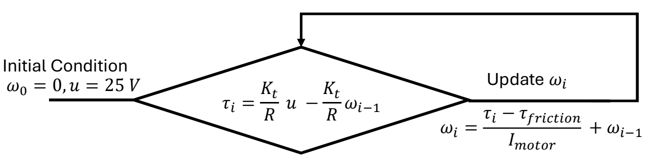


Fig 1. Actual Shutter with Optical stand (left) CAD rendering of Shutter design(right)

We designed a **noise-minimized** mechanical optical Shutter via **electrical deceleration**. We also selected two best performing motors – a big and a small one – via **motor simulation.**

Motor Characterization

- A DC motor can be characterized as a series of a resistor and an inductor.[2]
- With an applied voltage **u,** a motor simulation with torque constant K_t, Resistance **R,** can be characterized as:



- Torque constant K_t describes the relationship between generated torque and input current. It is positively correlated to rotor inertia and back EMF is proportional to the torque constant.
- Through evaluating the maximum allowable input power, the best motors are:

	$K_t \left[\frac{Nm}{A}\right]$	$R[\Omega]$	Rotor Inertia [g cm^2]
PAN14EE12AA1 (big)	0.007653	2.6618	1.799
PKN12EB105C1 (small)	0.002858	9.527	0.2625

Fig 2. Chart of the physical properties of the best motors: Torque constant, Resistance, and Rotor Inertia

Shutter Controller

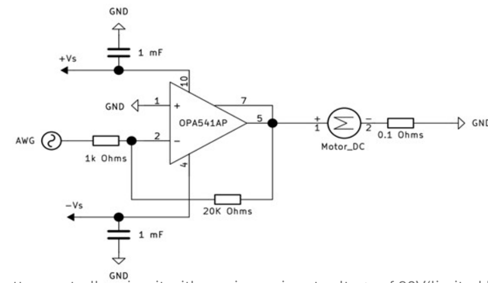


Fig 3. Shutter controller circuit with maximum input voltage of 80V(limited by Op-amp)

- The shutter controller uses OPA541AP-ND Texas Instrument for bipolar driving.
- AWG for input waveform customization

Experimental Sequence

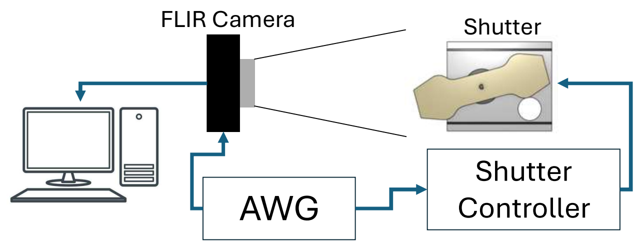


Fig 4. Shutter measurement system where FLIR camera captures image at 1000HZ

- camera and shutter are passed with waveforms of 1 ms delay.
- The input waveform is a square wave where the negative peak is 95% of the positive peak to account for friction.

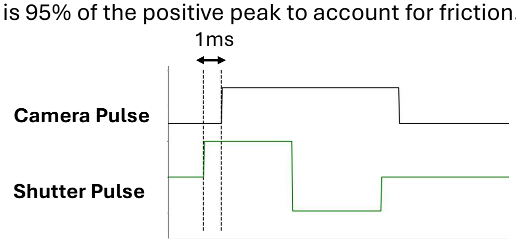


Fig 5. Camera Pulse can sweep through the shutter pulse at a timestep of 1ms.

- The negative shutter pulse brings electrical deceleration such that the blade hits the physical stop at a slow velocity.

[1] Zhang, G. H., Braverman, B., Kawasaki, A., & Vuletić, V. (2015). Note: Fast compact laser shutter using a direct current motor and three-dimensional printing. *Review of Scientific Instruments*, *86*(12). https://doi.org/10.1063/1.4937614
[2] *Introduction to Robotics*, H. Harry Asado, 2011 https://people.csail.mit.edu/jbarry/spring2011PR2/readings/asado.pdf

Results

Big Motor:

- Closing time is determined when the motor blade travels to - 16 degree, when the aperture is fully blocked.

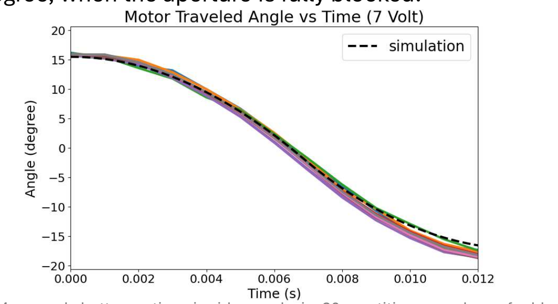


Fig 6. Measured shutter motion via video analysis. 20 repetitions are shown for blade motion at 7V for aperture of 10mm diameter. Solid lines are experimental data.

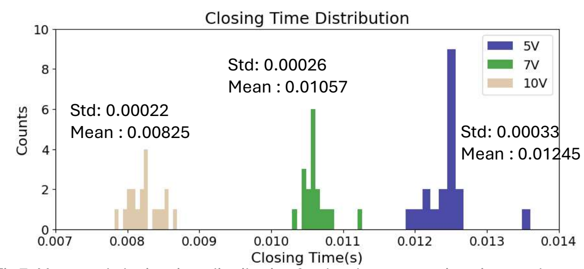


Fig 7. Measured closing time distribution for the shutter at various input voltage.

Small Motor:

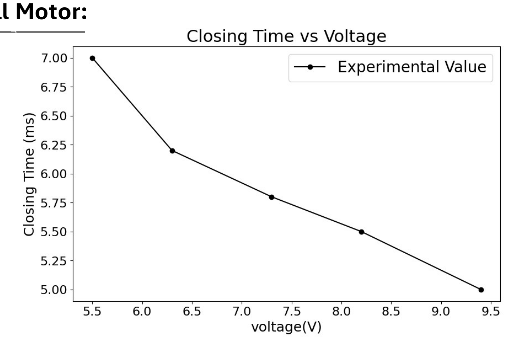


Fig 8. Measured shutter motion via video analysis for small motor at five different input voltages for aperture of 3mm diameter.

Summary

The **big motor** can close in around 8 ms for an aperture of 10mm; the **small motor** can go down to 5 ms with a 3mm aperture

Limitation

Applying electrical stop increases the minimum closing time. Motor's back EMF becomes significant as input waveform Vpp goes beyond 30V