The Advance of Laser Radar by Using Varioptic Tunable Liquid Lens

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Abstract

Accurate detection and identification of insects are important for ecological monitoring and pest management in agriculture. Laser radar systems often need help with precision due to variable environmental conditions and target sizes. We explore the application of a Varioptic® liquid lens (Corning, NY) to enhance the resolution of laser radar systems in detecting and identifying insects. The Varioptic® liquid lens with adjustable focal length is controlled by LabView software integrated into a laser radar system. The LabView code will be developed and tested with the demo laser radar available at the Remote Sensing Lab of the Grove School of Engineering, CCNY. Previous results indicated a significant improvement in the detection resolution of the signal, particularly at different distances. Using the Varioptic® liquid lens allows for a higher signal-to-noise ratio value and ensures a better detection of insects. This advancement in laser radar technology presents a promising tool for more effective monitoring and pest management.

Laser Radar Schematic

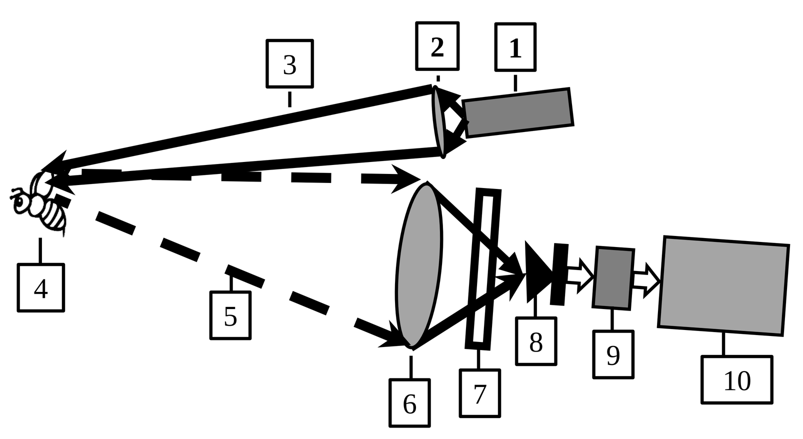

Figure 1. Laser Radar For Flying Object Detection.

1. Laser
2. Varioptic Liquid Lens
3. Laser Radiation
4. Flying Object
5. Reflected Rays
6. Concave mirror
7. Narrow-Band Filter
8. Photodetector
9. Oscilloscope
10. Computer with Signal Filtering software and Liquid Lens control software

Varioptic Liquid Lens Structure

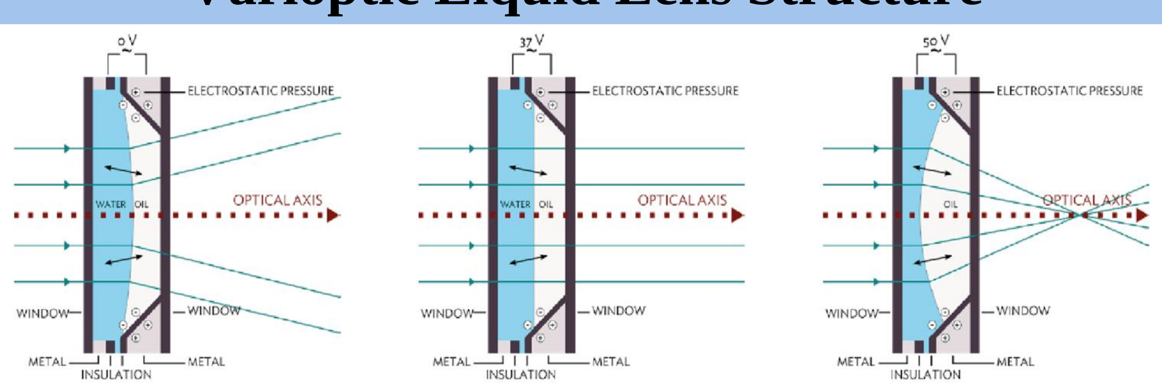

Figure 2. Varioptic Liquid Lens .(Corning,2024)

The design of the adjustable lens structure ensures:

- Stable optical axis, by a conical centering of the drop
- Non-sensitivity to orientation, by using two liquids of equal density
- High shock resistance by a simple mechanical structure and equal density

Depending on the voltage applied, the lens can be a divergent lens, a flat lens, or a convergent lens (Corning, 2024).

Signal Analysis and Application of the Liquid Lens

The acquired signal is being filtered and processed through the MatLab software, which allows us to see the filtered signal. After filtering the signal, we calculate **the Signal-to-Noise(SNR) ratio by using the** build-in command **snr(x, fs, n),** where **x** – input signal, **fs** - sample interval, **n** – number of harmonics**,** determine how the Liquid Lens improves the Laser Radar detection ability. All signal data was collected from the test drone propeller at distance of three meters from the laser telescope to the drone propeller. This way, we compare the data and ability of the Liquid Lens and Two Lens setup to improve signal detection.

Potential Challenges of the Liquid Lens

Outdoor conditions and changing weather cause challenges to the performance of liquid lenses. Temperature fluctuations can alter the liquid's viscosity and surface tension, affecting the lens's ability to maintain a consistent focal length. High temperatures cause expansion or evaporation of the liquid, while cold conditions could reduce responsiveness, leading to performance degradation. Humidity and rain can introduce condensation or water droplets on the lens surface, disrupting light transmission and reducing image clarity.

Signal Analysis of the Liquid Lens

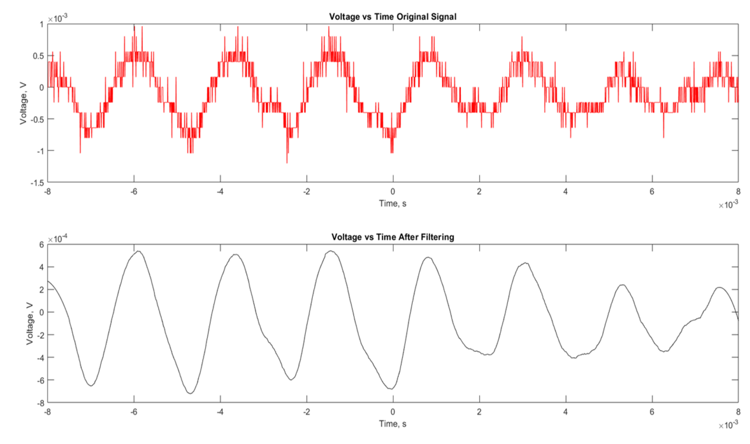

Figure 3. No Lens Signal before and after filtration.

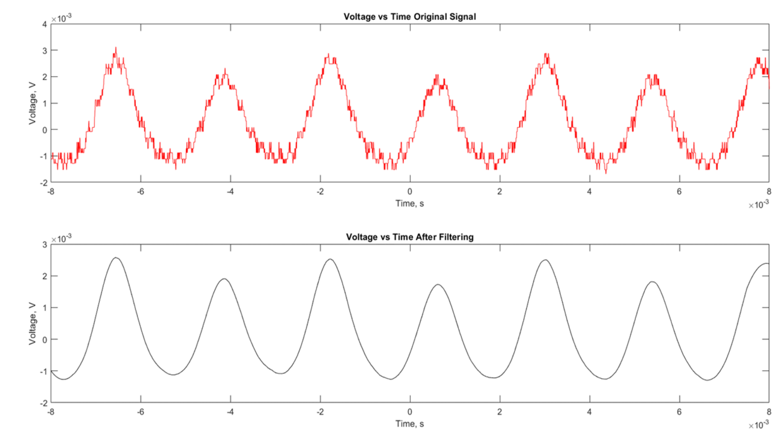

Figure 4. 24V Signal before and after filtration.

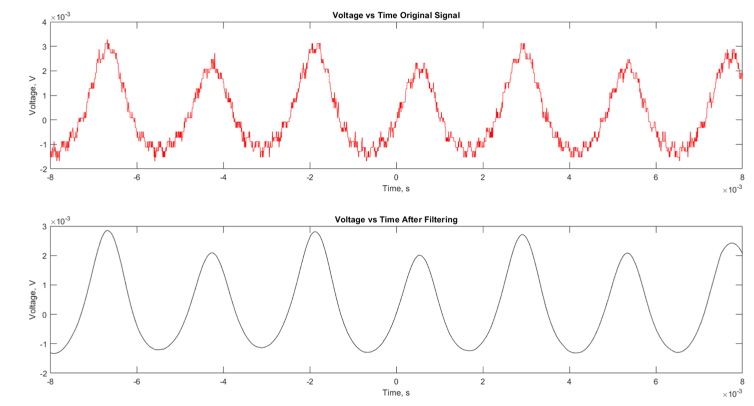

Figure 5. 31 V Signal before and after filtration.

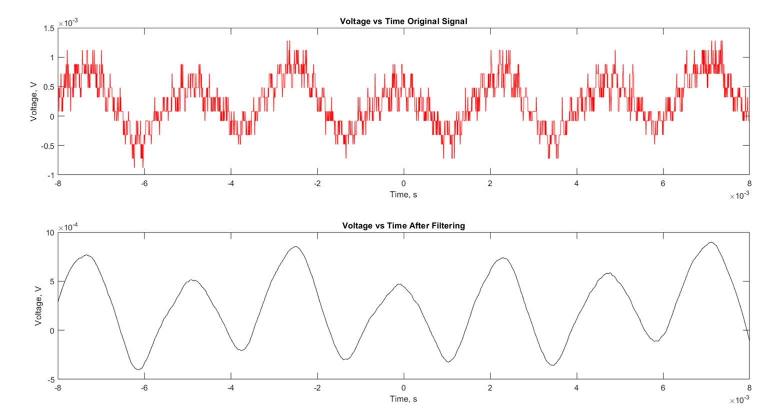

Figure 6. 45 V Signal before and after filtration.

The Laser Radar system without a liquid lens produces a noisy signal, with an unfiltered SNR of 9.87 dB, improving to 42.72 dB after filtering. Adding a liquid lens powered at 24 V provides a steadier signal, further refined using MatLab, boosting the SNR from 15.49 dB to 46.51 dB. Adjusting the voltage to 31 V optimizes the lens's focus on a drone propeller, increasing the SNR from 15.81 dB to 48.25 dB after filtering. Testing the lens off-focus at 45 V yields a noisy but stable signal with an SNR of 3.65 dB, improving to 35.18 dB after filtering, demonstrating the liquid lens's overall effectiveness in enhancing signal quality.

Voltage, V	Signal-to-noise ratio before filtering	Signal-to-noise ratio after filtering
24	15.4933	46.5040
31	15.8138	48.2474
45	3.6529	35.1837
No lens	9.8663	42.7199

Figure 7. Table of Signal-to- Noise ratio for different Voltage of Varioptic Liquid Lens .(Corning,2024)

Two Lens Laser Radar Setup

The liquid lens in a laser radar system can be substituted with a two-glass-lens setup configured as a Keplerian beam telescope to achieve similar functionality. This setup uses a convex lens as the input and a second convex lens with a shorter focal length as the output. The first lens focuses the incoming beam to a point, while the second lens collimates and expands the beam, enhancing its diameter and reducing divergence. By precisely aligning the lenses and selecting appropriate focal lengths, this configuration can dynamically adjust focus and expand the beam, mimicking the adaptive properties of a liquid lens, though without its electronic tunability.

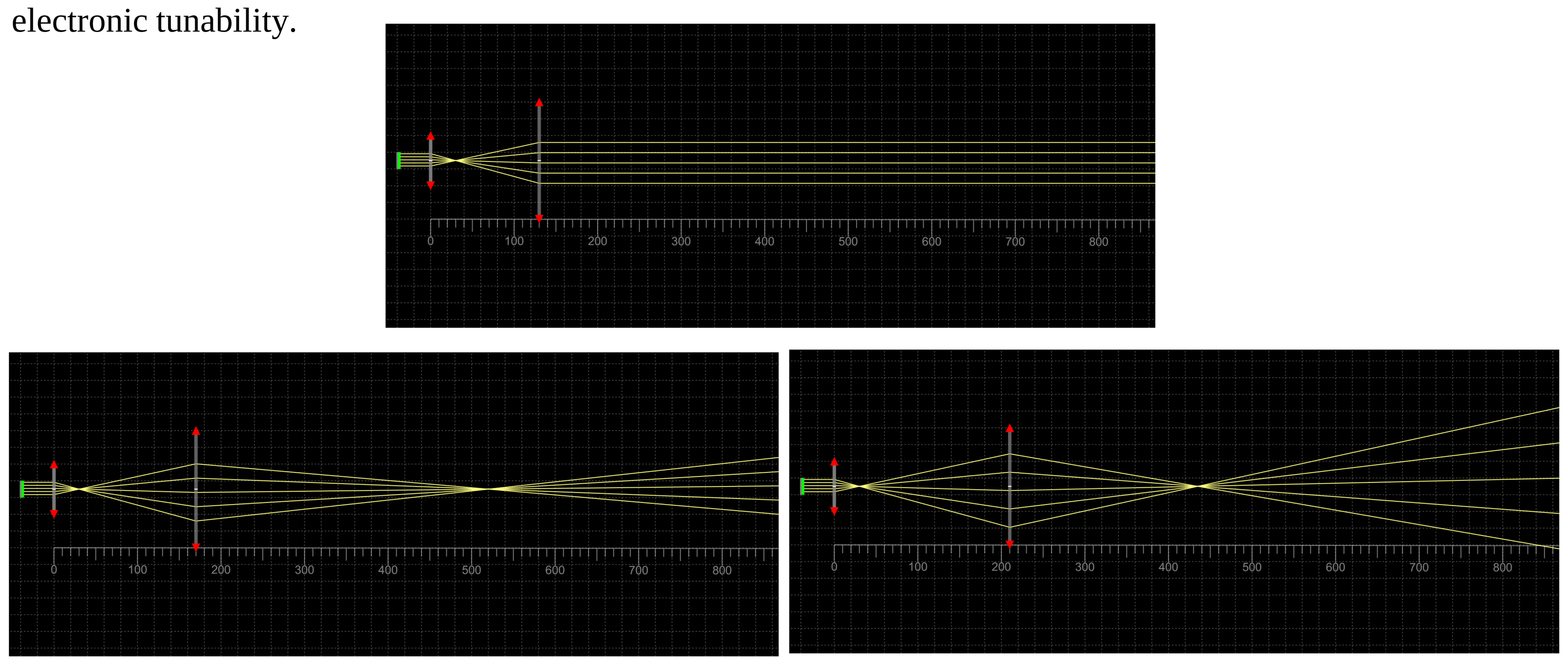

Figure 8. Simulation of two lens setup (30 mm and 100 mm focal length) .(Ray Optics Simulation, 2024)

The two-lens setup in the laser radar system acts as a beam expander, significantly improving signal quality and focus precision. By using a convex input lens to focus the beam and a second convex output lens to expand it, the system reduces beam divergence and enhances detection accuracy over longer distances. This configuration allows for a more consistent and amplified signal, improving the system's ability to distinguish between objects and reducing the noise-to-signal ratio. The precise alignment and focal adjustments of the lenses provide a reliable alternative to adaptive liquid lenses, especially in controlled settings.

Two-Lens Setup Signal Analysis

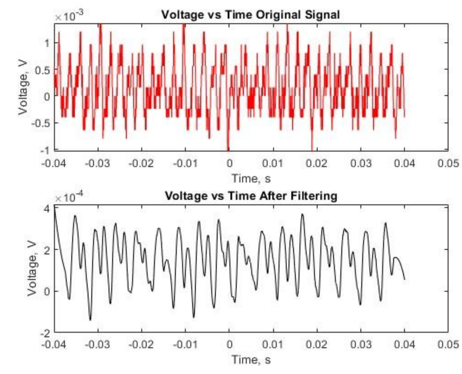

Figure 9. No Lenses signal before and after filtering.

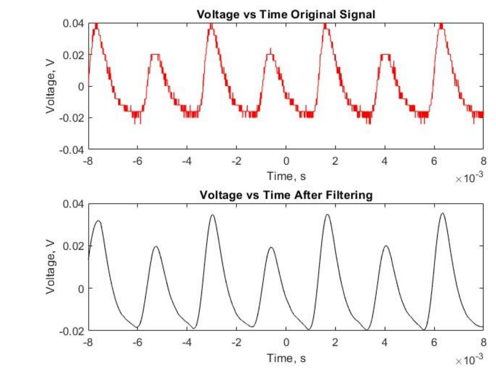

Figure 10. -5 mm from focus signal.

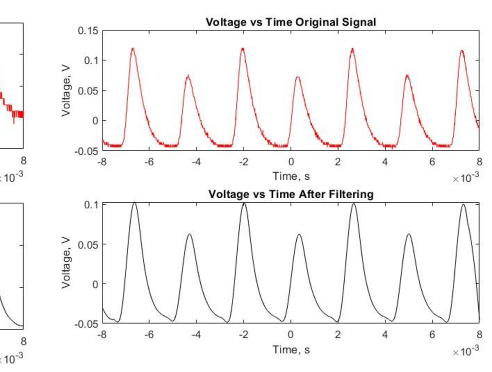

Figure 11. -3 mm from focus signal.

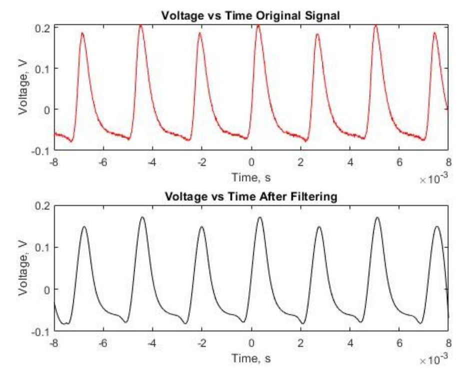

Figure 12. In focus signal.

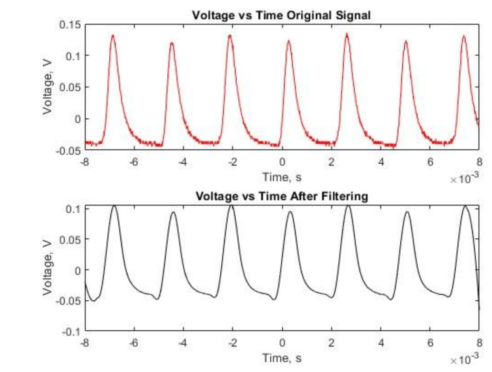

Figure 13. +3 mm from focus signal.

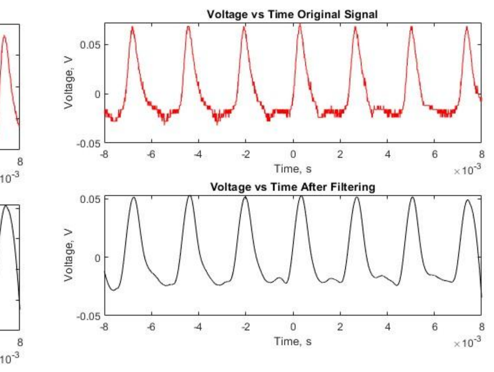

Figure 14. +5 mm from focus signal.

Distance	Signal-to-noise ratio before filtering	Signal-to-noise ratio after filtering
-5 mm	15.9490	20.3383
-3 mm	20.4521	21.5839
0 mm	29.2309	54.5521
3 mm	26.1785	48.3321
5 mm	19.3063	50.3674
No lenses	3.4046	15.3049

Figure 15. Signal-to-Noise ration before and after filtering on different distances to and from focus.

Initial testing of the two-lens setup provided promising insights into its potential implementation in the laser radar system. The configuration effectively improved signal clarity and focus, demonstrating its ability to enhance detection accuracy. However, a key challenge is the manual adjustment of the distance between the lenses, which must be highly precise to maintain proper alignment of the laser beam on the target. Additionally, the setup's sensitivity to external vibrations and can disrupt the alignment, requiring improvement of the system. Despite these challenges, the results highlight the setup's potential as a cost-effective and reliable alternative to adaptive liquid lenses.

Conclusion

The Varioptic Liquid Lens has demonstrated good results in improving signal detection in laser radar systems for identifying insects and other flying objects. Its ability to seamlessly adjust focus enhances signal detection, enabling efficient filtering and precise calculation of the chopping rate, which is crucial for identifying the type of object detected. On the other hand, initial testing of the two-lens setup has shown promising potential as an alternative, taking to account disadvantages of the liquid lens. By expanding the laser beam, the setup improves signal clarity and detection accuracy. However, challenges remain with precise manual adjustments and sensitivity of the two-lens setup. Together, these innovations open the way for advancing laser radar systems toward the automatic detection and identification of flying objects, offering flexible solutions for various applications.

Acknowledgement

This research project was supported by NSF REU Grant AGS-2150432, NSF IUSE Grant ICER-2023174, and Pinkerton Foundation (HIRES).). The authors would like to express their gratitude to their faculty advisor, Dr. Andrii Golovin, for the amazing opportunity, guidance, and help provided during the research project. The statements contained within the poster do not represent the opinions of the funding agency or the U.S. government but reflect the authors' opinions.

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