Real-time building air leakage visualizer

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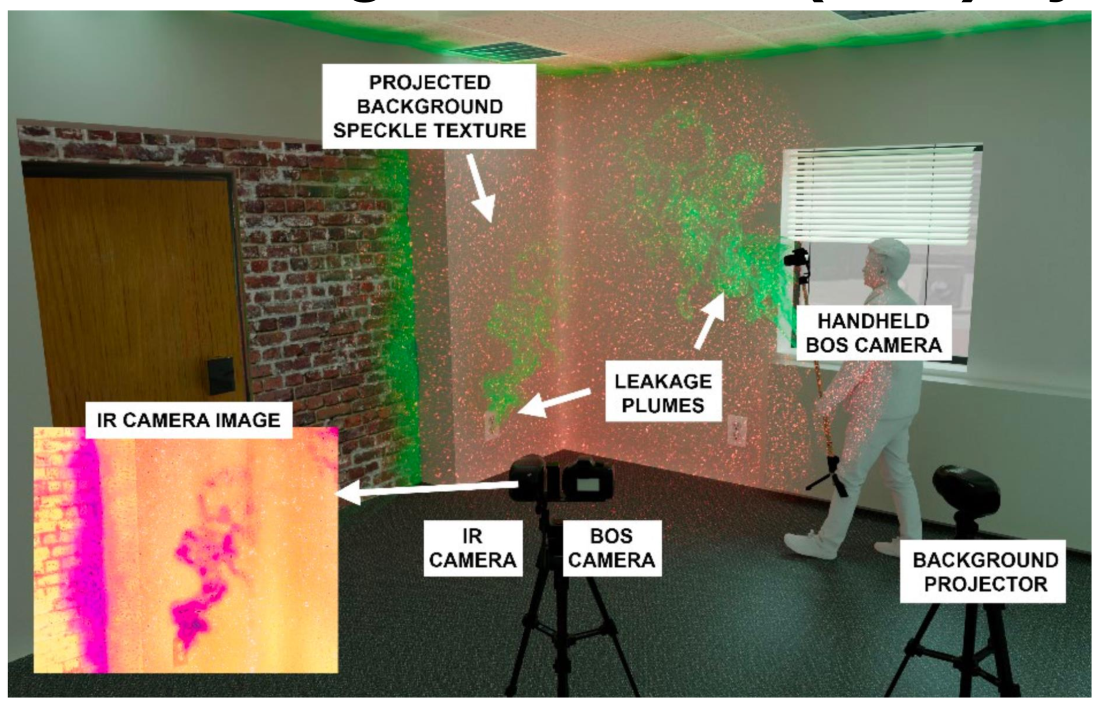
Abstract

Energy audits are critical for improving building efficiency and are often necessary for commissioning and green renovation projects. Key aspects of these audits include utility analysis, walk-throughs, and system evaluations. One of the primary contributors to energy loss is building air leakage, which results in an estimated 4 quads (1172 TWh) of wasted energy annually in the U.S. Traditional methods, such as blower door tests, are often disruptive and time-consuming, particularly for large buildings. This work explores the adaptation of the background-oriented schlieren (BOS) imaging technique to visualize air leakage in situ and in real-time. Leveraging natural temperature differences, BOS can detect air infiltration and exfiltration without the need for seeding agents. Previous studies have validated its use in HVAC systems and laboratory settings, and this project aims to scale its application for full building assessments.

Air Leakage Visualizer (ALV) system



The ALV system to be developed outlined in Figure 1 will image air leakage through a building envelope by integrating BOS and thermal imaging to identify and quantify leakage locations and flow rates. The ALV system will include drone-based and manually carried platforms for efficient sampling.

Figure 1: ALV system concept

Fundamentals of background oriented schlieren

Background oriented schlieren is an imaging tool used to visualize changes in refractive index and is useful for situations where more complex optical systems cannot be used [1]. For BOS, a camera records an event that causes refractive disturbance against a patterned, typically random, background. Often a printed background is used, but any random pattern can be used ranging from projected speckles to the natural landscape of a hill. Refractive disturbances cause the camera to visualize pixel shifts in the background, which can be measured and correlated to the physical change in the test section. The BOS setup used at NMT is seen in Figures 2 and 3. Ideally, the *t/l* distance should be between 0.5 and 0.75 [2], however in this application the *t/l* distance will be <0.5, which lessens the sensitivity of the system. BOS imaging development is ongoing at New Mexico Tech as well as Oak Ridge as shown Figure 4.

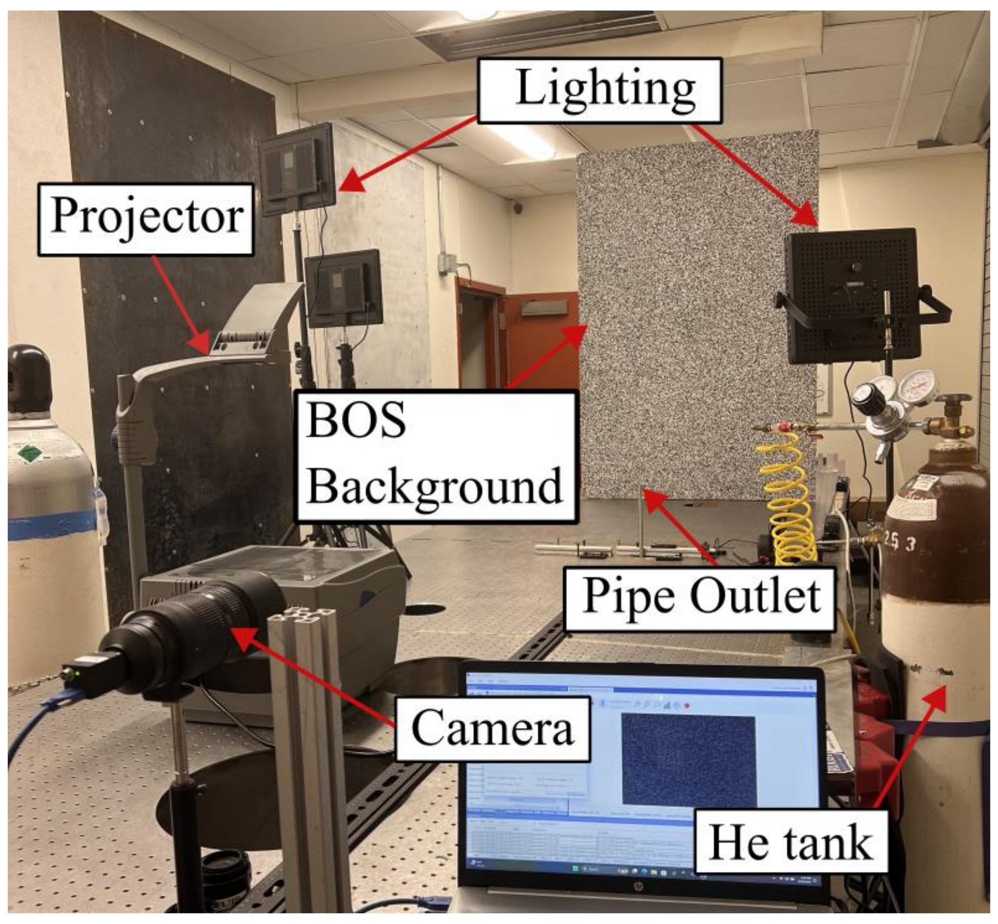


Figure 2: Laboratory BOS setup for imaging helium plumes against a BOS background

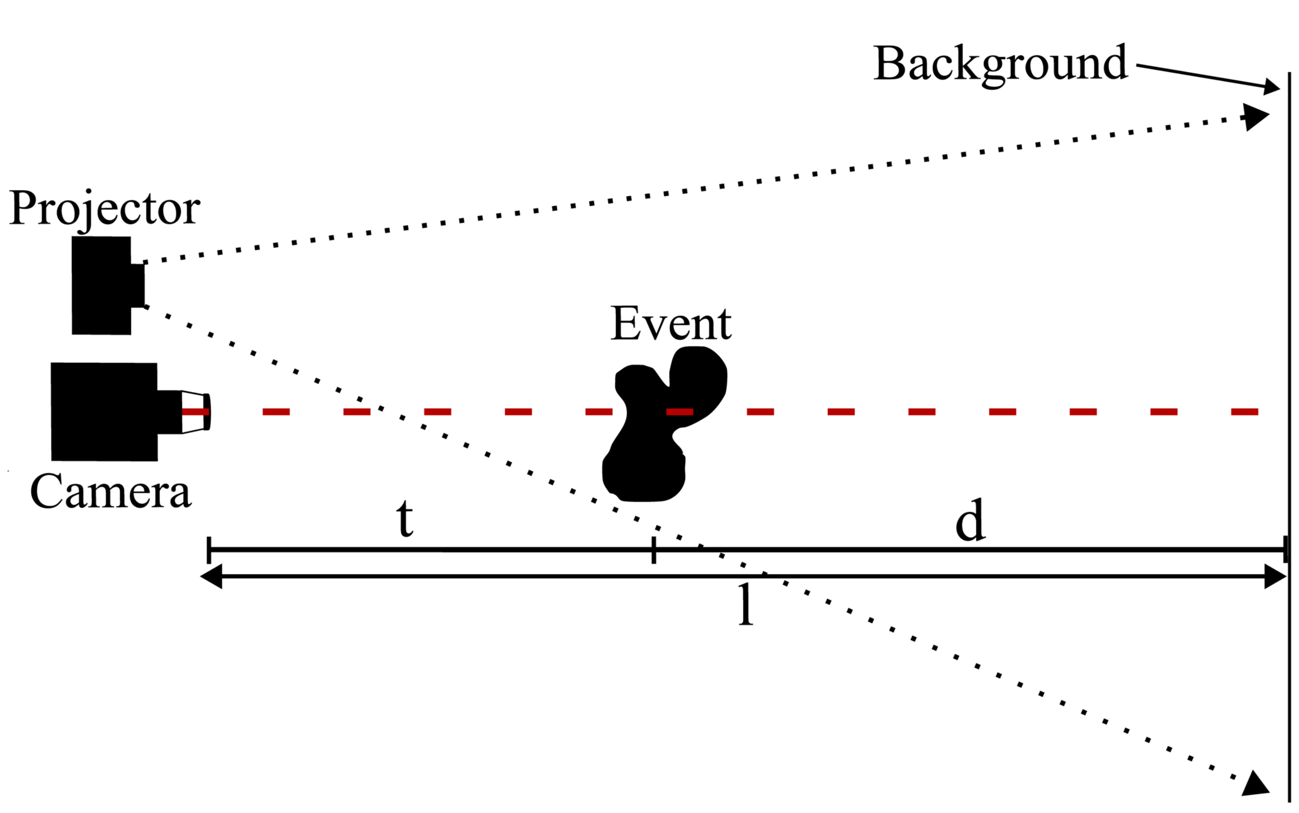


Figure 3: Top-down schematic of laboratory BOS setup.

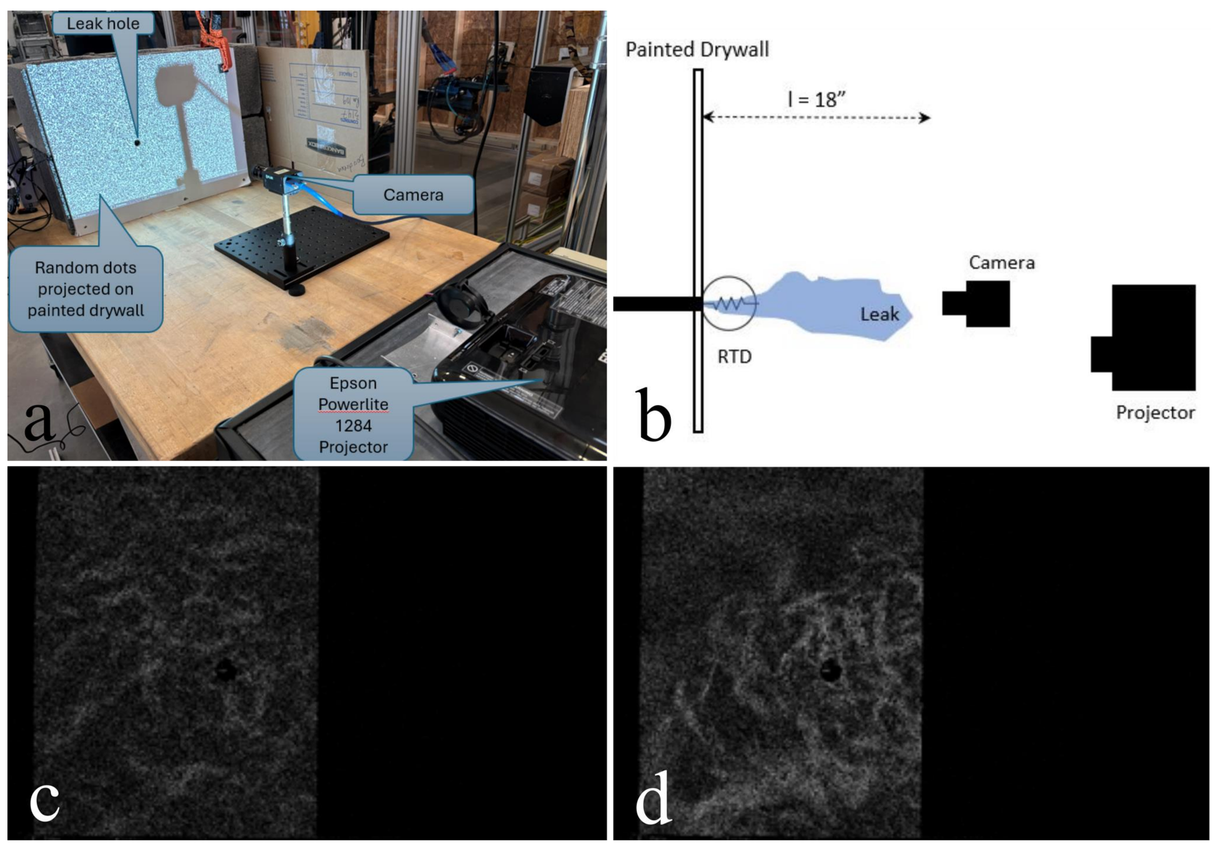


Figure 4: BOS progress at ORNL of a simulated leak from a CMU wall showing (a-b) setup and (c-d) results.

Initial BOS imaging results

Preliminary results include imaging helium plumes against projected BOS backgrounds shown in Figures 5 and 6. These images are processed by first registering all images to the initial frame, then processing through the Horn–Schunck method of optical flow, and finally, averaged over time to detect the plume.

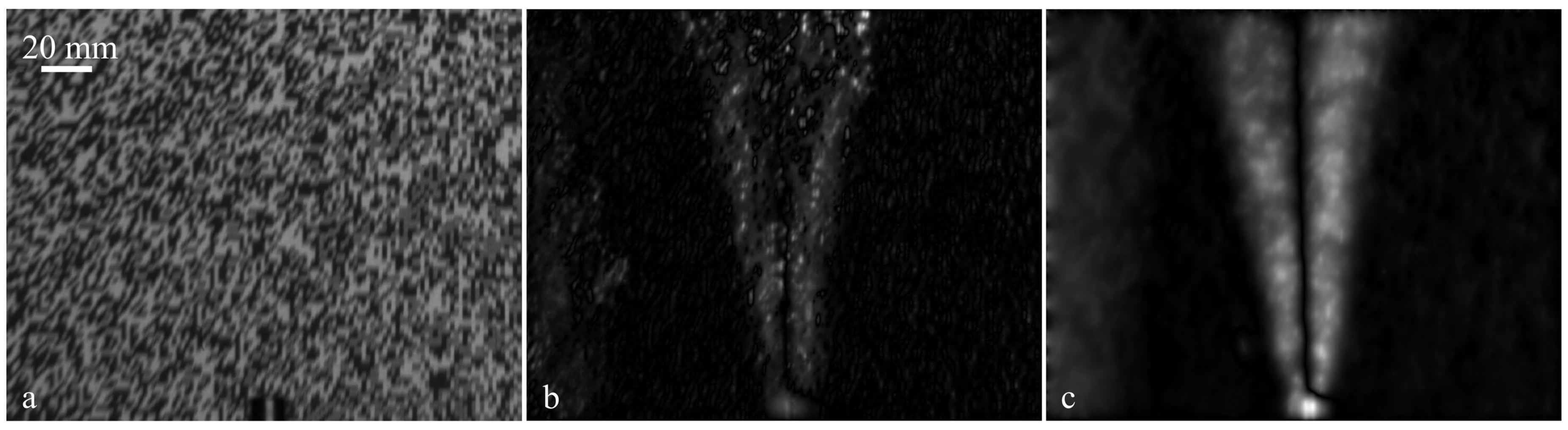


Figure 5: Images for a helium plume with *t/l* distance of 0.5, where (a) is the raw BOS image, (b) is a single frame registered to the first frame and processed through optical flow, and (c) is the average of 50 processed images.

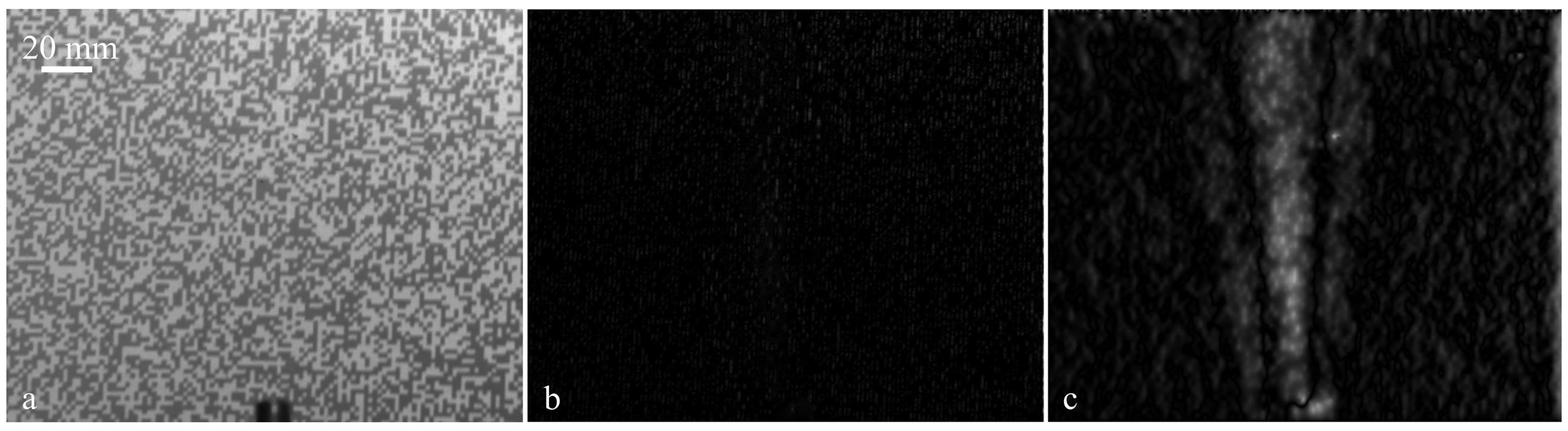


Figure 6: Helium plume with *t/l* distance of 0.07, where (a) is the raw image, (b) is a single processed frame, and (c) is the average of 50 processed images.

Three-dimensional leakage mapping at scale

Technologies developed and integrated by Joulea have allowed correlation between visual spectrum and thermal images recorded from aerial drones. As shown in Figure 7, thermal images identify building leakage. Ultimately, the aligned visual images will be used for BOS processing. All aerial images are then correlated to known locations on the subject building as shown in Figure 8.

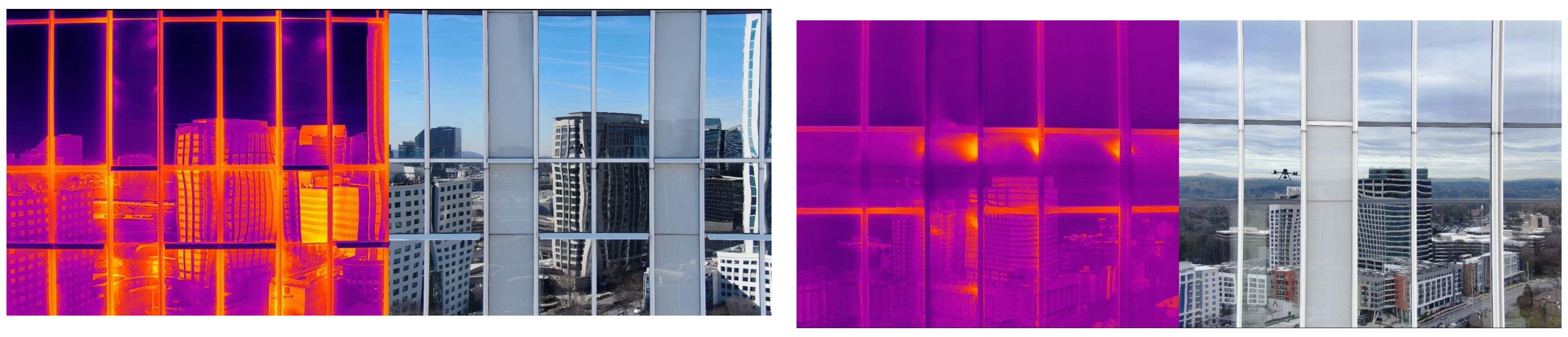


Figure 7: Drone recorded thermal and visual images with leaks visible

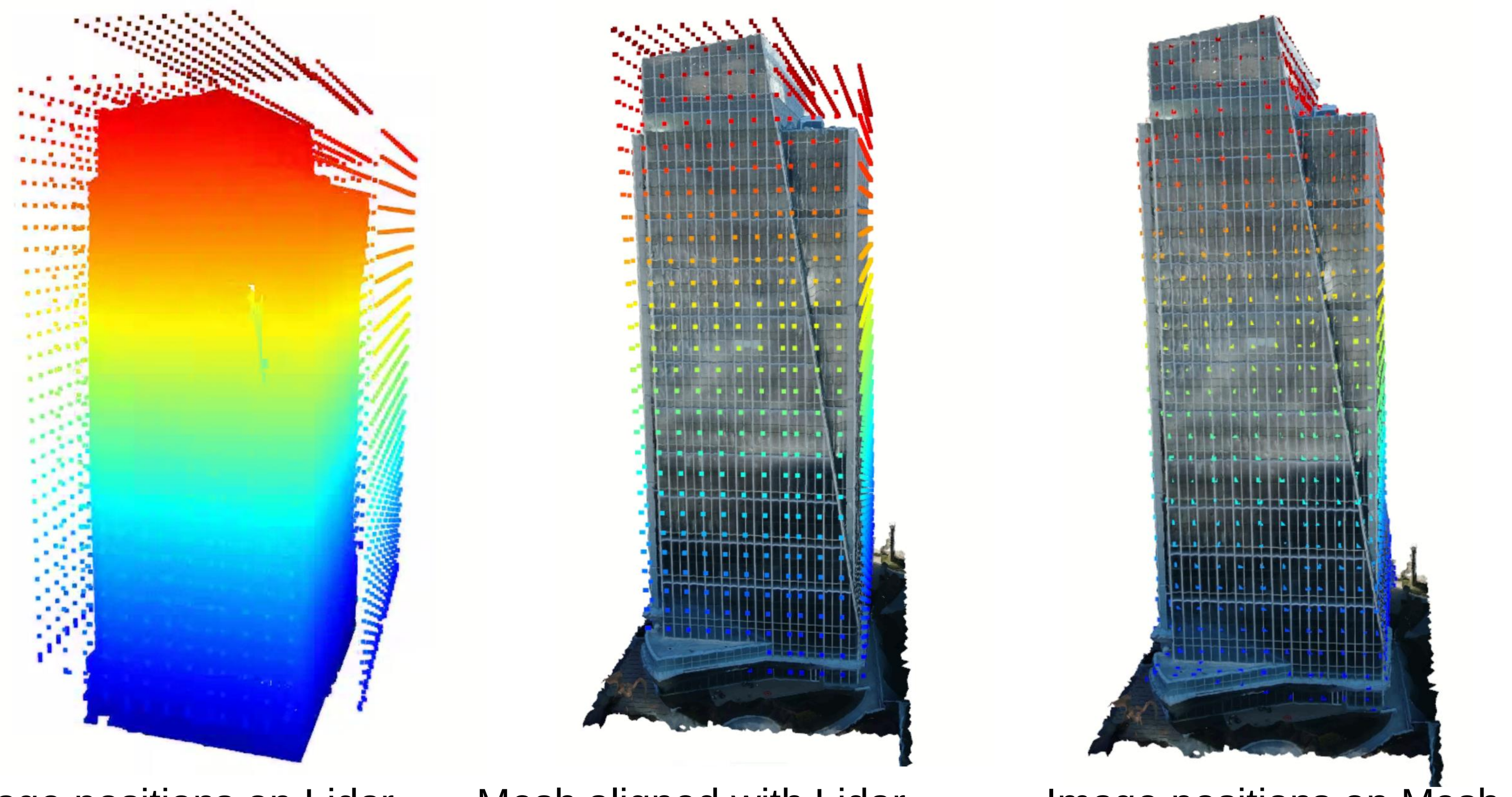


Image positions on Lidar | Mesh aligned with Lidar | Image positions on Mesh

Figure 8: Projecting drone recorded images onto mesh

Conclusions and Ongoing Work

Initial results from the start of this multi-year project demonstrate the ability to perform BOS visualization of leaks as well as aerial detection via thermal imaging. Currently the team is improving upon these processes and integrating technologies including fusion of BOS and thermal imaging, incorporating real-time processing, improved BOS background projection schemes, and deploying high fidelity cameras on our drone platform for BOS.

References and Acknowledgements

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