Reconstructing 3D Thermal Profiles of Buildings using Multimodal Drone Data

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1. INTRODUCTION

- 44 % of U.S. homes built before 1970 suffer from poor insulation and energy loss.
- LiDAR surveys are precise but cost-prohibitive; typical drones carry low-resolution thermal sensors.
- We present an affordable drone workflow that merges infrared and high-resolution RGB images with Structure from Motion to produce dense three-dimensional thermal maps.

2. BACKGROUND

Structure-from-Motion (SfM) in Civil Engineering
- SfM reconstructs 3D models from 2D images by estimating camera pose and geometry [1].
- It's a cost-effective alternative to LiDAR for structural modeling [2].
- Tools like COLMAP have made SfM scalable and robust for large datasets [1], [3].

UAVs for Infrastructure Inspection
- UAVs combined with SfM are widely used for buildings, bridges, and topographic mapping [2], [4].
- Allow efficient, multi-angle data collection in hard-to-reach areas [5].
- Effective in construction, tunnel, and highway inspections [6], [7].

Limitations of RGB-Only Models
- RGB images capture visual detail but lack thermal data, missing defects like heat loss or poor insulation [8].
- Dense point clouds from RGB alone do not support energy diagnostics.

Thermal Imaging: Value and Challenges
- Thermal sensors detect surface temperature variations for identifying leaks and insulation flaws [9], [10].
- However, thermal imagery is typically low-res and prone to distortion, limiting its 3D usability [11].

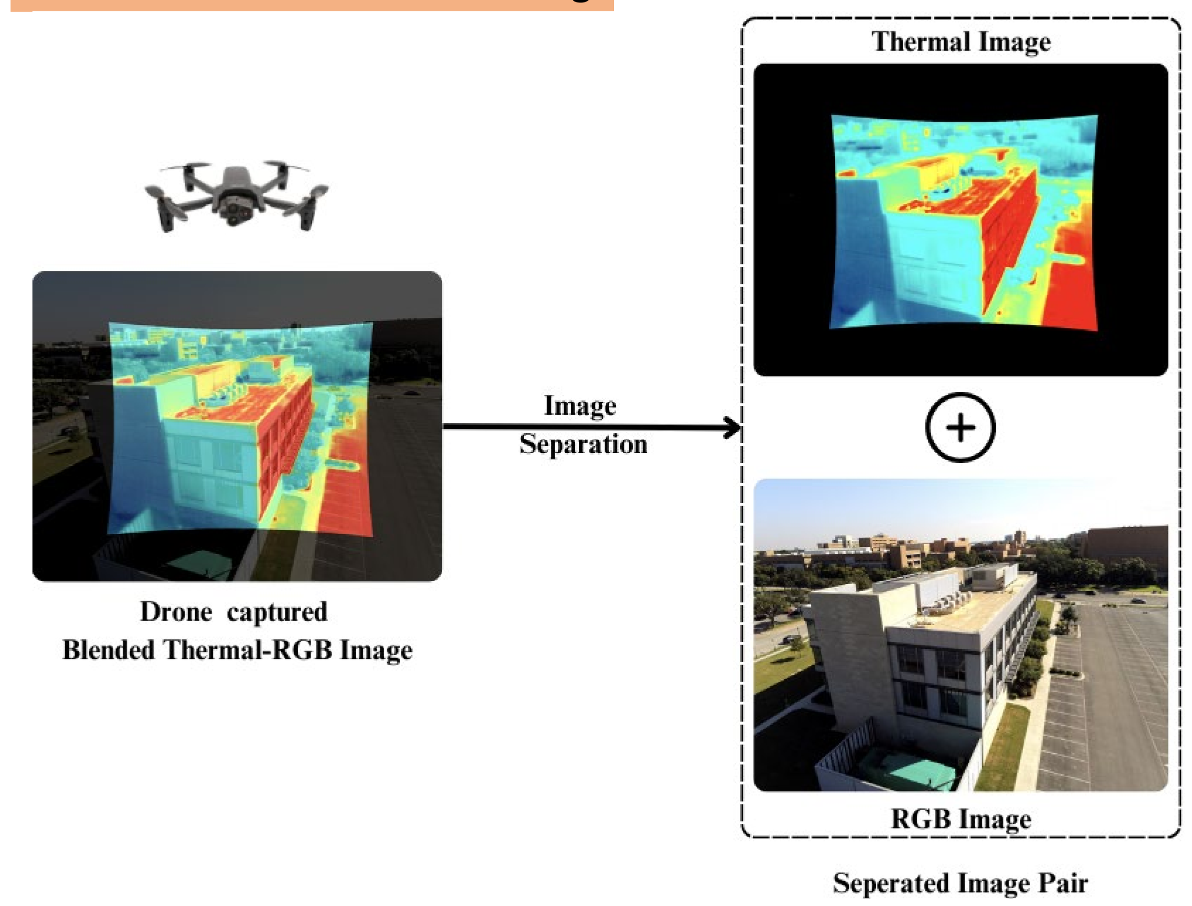
Fusing RGB and Thermal Data
- Fusion enhances 3D models with both spatial detail and functional thermal data [12].
- Earlier methods were limited to sparse fusion and lacked resolution [11], [12].
- Recent advances embed thermal values into dense point clouds using techniques like KNN [11], [13].

3. OBJECTIVES

I. Fuse drone-captured low-resolution thermal data with high-resolution RGB imagery to generate a dense, thermally enhanced 3D point cloud
II. Leverage drone-based sensing for automated, contactless thermal assessment of building envelopes
III. Develop a scalable, low-cost inspection pipeline using open-source SfM tools
IV. Enable future integration with deep learning for robotic thermal anomaly detection in built environments

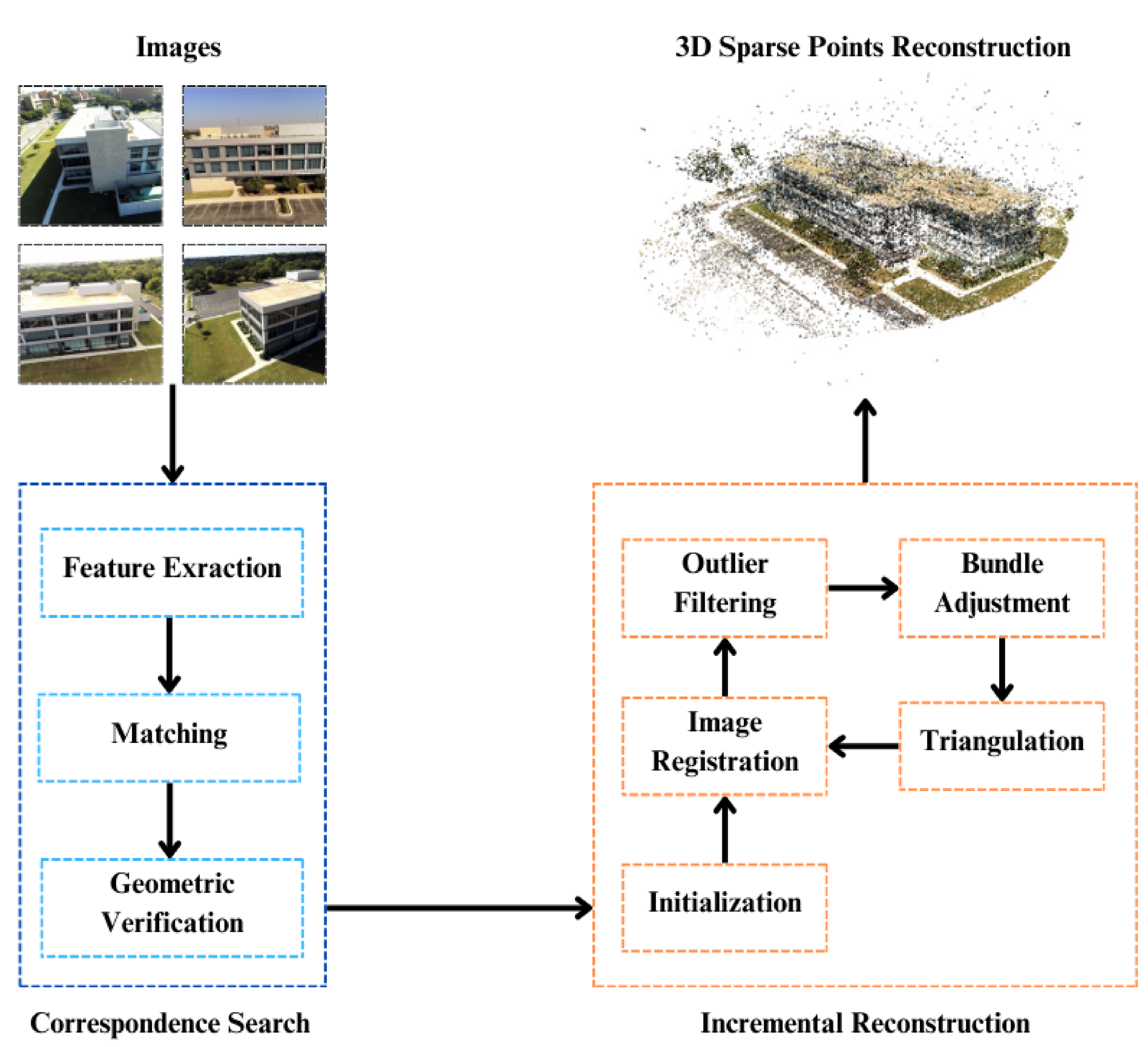
4. METHODOLOGY

I. Data Collection and Processing



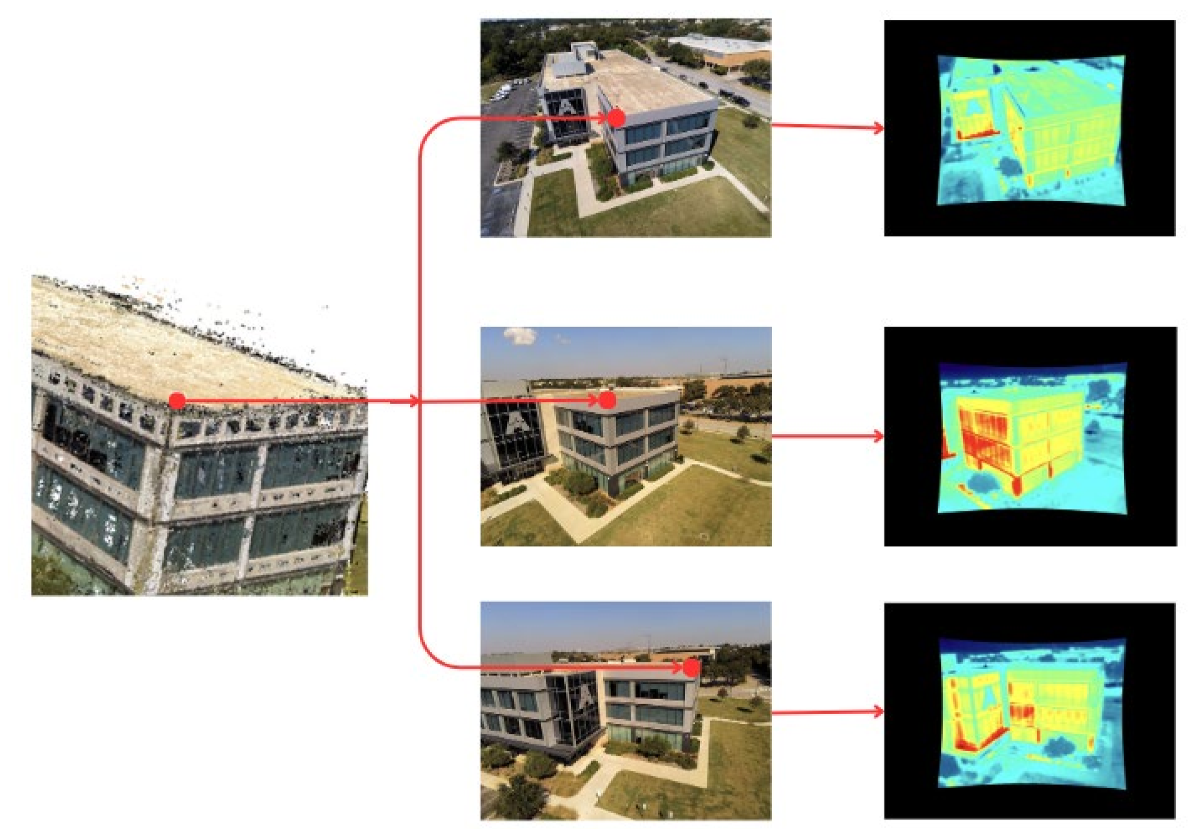
- Location: Trinity Hall, UTA
- Drone: Parrot Anafi USA with 4K + FLIR Boson® IR
- 417 images captured at 10'', 20, 30' elevations
- RGB and thermal channels separated from blended images

II. RGB Sparse Reconstruction



- Tool: COLMAP (SfM + SIFT)
- Sparse 3D points from RGB feature matches
- Sequential matching used for efficient registration

III. Thermal Sparse Mapping



- Back-project sparse RGB points to original images
- Map to corresponding thermal pixels
- Convert thermal RGB values to temperature index
- Filter using IQR-based outlier detection
- Final thermal value = median of inlier pixel values

IV. Dense Reconstruction

- A dense RGB point cloud was generated using Multi-View Stereo (MVS) in COLMAP.
- This provided high-resolution geometry but lacked thermal information.

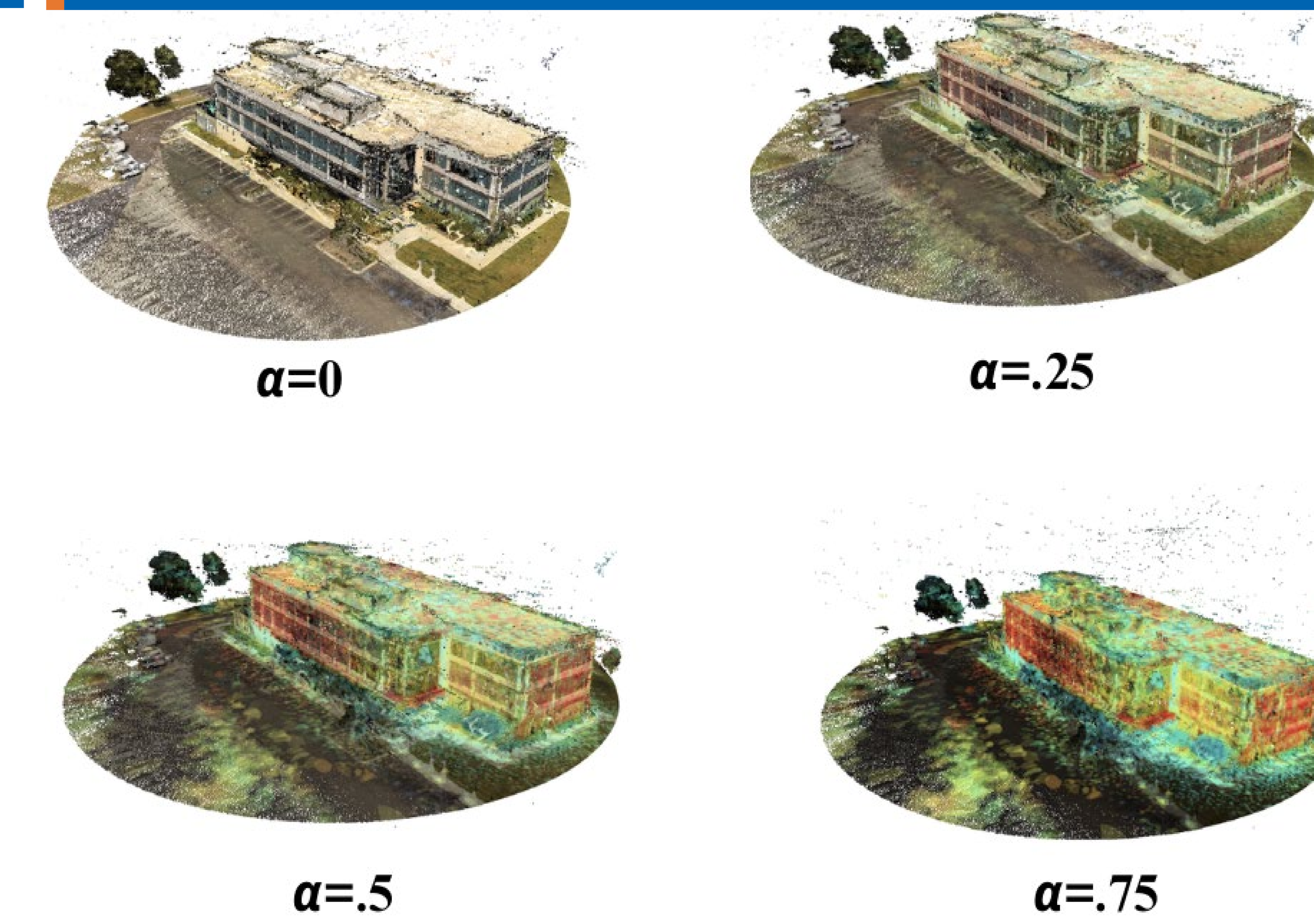
Thermal Value Interpolation using KNN
- For each dense point p_{dense}, K-Nearest Neighbors (K = 3) was used to find nearby sparse points with known thermal values.
- The thermal value was computed as the average of these neighbors:

$$T(p_{dense}) = \frac{1}{3}\sum_{i=1}^{3} T\left(p_{sparse(i)}\right)$$

RGB–Thermal Blending
- RGB and thermal data were blended for visualization using:

$$p_{\{blended\}} = \alpha \cdot p_{\{thermal\}} + (1-\alpha) \cdot p_{\{visible\}}$$

5. CASE STUDY AND RESULTS



- The method was tested on a desktop with an Intel i9 CPU and NVIDIA RTX 4090 GPU, ensuring fast and efficient processing.
- Sparse reconstruction produced ~107,000 points in ~15 minutes, capturing the building's base geometry.
- Dense reconstruction generated ~10 million points in ~30 minutes, offering high-resolution spatial detail suitable for inspection.
- Thermal values were accurately interpolated from sparse to dense points using KNN.
- Blending analysis with alpha values (α = 0.25, 0.5, 0.75, 1.0) showed: α = 0.5–0.75 provided the best visual balance.
- Final outputs preserved both geometric structure and thermal information, supporting manual review and future AI-based anomaly detection.

6. CONCLUSION

- Demonstrated a drone-driven workflow for creating high-resolution 3D thermal models of buildings based on our recent work [14].
- Achieved effective fusion of thermal and RGB drone imagery using an open-source SfM pipeline (COLMAP)
- Produced dense point clouds with embedded temperature values, enabling detailed thermal profiling
- Validated that the method can highlight thermal anomalies such as heat loss and insulation defects

Future Work:
The next phase involves integrating this pipeline with deep learning frameworks for thermal defect detection and scaling it toward autonomous, drone-based building inspection systems in construction and facility management. We also plan to evaluate model accuracy using ground-truth thermal or LiDAR references and scale deployment to large infrastructure systems.

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https://iset-lab.github.io

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