A Portable System for Real-Time Short-Range 3D Thermal Digitization of Objects

by A. Sánchez*, A. Adán*, E. Adán

* *University of Castilla-La Mancha, Soft Robotics and 3D Computer Vision Lab, Ciudad Real, Spain*

Abstract

This article addresses the challenge of obtaining dense and spatially coherent three-dimensional thermal information in short-range thermal digitization processes, where small- and medium-sized objects require an accurate representation of both their geometry and thermal distribution. To this end, a portable and easily deployable system is presented, capable of generating dense 3D thermal point clouds using two RGB cameras and one thermal camera. Among the main advantages of the system are its original calibration method, high precision, and real-time performance. Several real case studies are presented at the end of the document.

1. Introduction

Conventional two-dimensional thermography techniques, although widely used for object inspection and thermal analysis, provide only a partial view of thermal phenomena due to the lack of complete geometric information and three-dimensional spatial referencing. In this context, 3D thermal point clouds emerge as a suitable solution for the unified integration of geometric and thermal information, enabling a more complete and accurate characterisation of digitised objects in controlled environments.

Several solutions addressing the problem of 3D thermal information acquisition have already been reported in the literature. In direct thermal stereo approaches [1], the correspondence stage between thermal images becomes complex, error-prone, and results in low resolution. Hybrid RGB–thermal configurations aimed at multispectral depth estimation [2] are also of limited practical use. Approaches based on coupled LiDAR devices and thermal cameras ([3]) are suitable for static scenes and offline processing scenarios, where data acquisition and processing are performed sequentially. In addition, the high cost of LiDAR systems further motivates the exploration of more affordable sensing alternatives. While complex multimodal configurations [4] (e. g. RGB camera, a thermal camera, and a LiDAR sensor) can provide satisfactory results, they come at the expense of high computational cost and limited portability, making them unsuitable for applications requiring sensor mobility. These approaches face limitations due to the difficulty of stereo matching and the challenge of extracting modality-invariant features across thermal and visible data.

2. The system SRTS

The proposed solution decouples geometric reconstruction from radiometric acquisition, enabling the generation of dense thermal point clouds with enhanced spatial detail. The system can be referred to as a Stereo RGB–Thermal System (SRTS) and consists of two main components: a stereo camera and an infrared camera.

The stereo camera is equipped with two sensors operating in the visible spectrum (RGB1 and RGB2) and incorporates a depth estimation system based on a neural network. In addition, it includes an integrated gyroscope and barometer. Key characteristics include a 120° wide-angle field of view (FOV), a depth range from 0.3 m to 20 m, and a maximum resolution of HD2K at a frame rate of 15 FPS. Experimental results obtained in laboratory conditions show that the distance error increases significantly as the stereo camera moves away from the scene, with errors below 1.5 mm for distances under 0.7 m.

The thermal camera, on the other hand, is a tCam-mini device with a resolution of 160 × 120 pixels, designed as an open-source solution for radiometric data acquisition. The thermal camera is positioned vertically aligned with the RGB1 sensor of the stereo system, as this sensor defines the reference coordinate system of the setup. Furthermore, the depth estimation process is carried out with respect to RGB1, and the resulting depth map is subsequently used to generate the thermal point cloud.

A custom extrinsic calibration method between the stereo camera and the thermal camera has been established, in which a small LED mounted at the end of a thin carbon rod acts as a visible and thermal emitting source. This marker is placed in the scene at different positions and depths, serving as a reference point. In this way, the luminous spot is easily detected by both the RGB1 camera (as a clear white light point) and the IR camera (as a radiating heat source), allowing the correspondence problem to be solved automatically. Once calibration is completed, the system enables real-time computation of the 3D coordinates of the point cloud.

The experimental validation of the system was carried out in different indoor and outdoor scenarios, covering environments with varying geometric and thermal conditions. Figure 1 shows two case studies. In the first scene, the RGB and thermal point clouds of three objects are presented against a white background. The traces left by a human hand (see red points) after arranging the scene are clearly visible, particularly on the helmet and the can. In the second scene, both point clouds capture the torso and face of a person. In this case, slight temperature variations across different facial regions can be observed, along with a high gradient relative to the clothing worn.

3. Conclusions

This paper presents a portable stereo-thermal system for generating thermal point clouds in real time. This capability significantly expands the range of potential applications, enabling its use in dynamic scenarios, rapid inspection tasks, continuous monitoring processes, or integration with robotic platforms and mobile acquisition systems. The immediate availability of three-dimensional thermal information is particularly relevant in contexts where real-time decision-making or iterative thermal evaluation is required.

The obtained results demonstrate the feasibility of the proposed approach and its ability to generate dense, coherent, and spatially consistent thermal point clouds. Overall, the experiments highlight the potential of the system as a foundational tool for the generation of advanced thermal models and its application in areas such as technical inspection, energy analysis, environment digitization, and three-dimensional thermal monitoring.

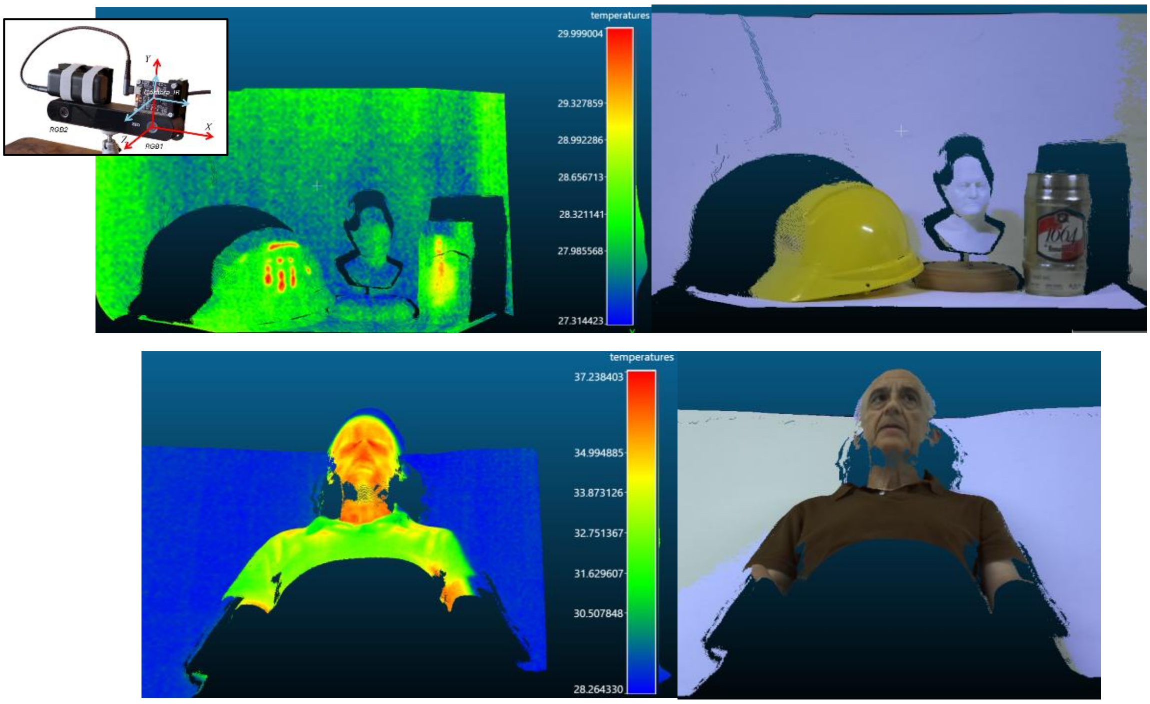

Figure 1. The system SRTS and results: RGB and thermal point cloud results obtained with the SRTS system in two case studies.

4. Acknowledgements

This work was supported by projects PID2022-141275OB-C21 (CIN/AEI/10.13039/501100011033/FEDER, EU) and SBPLY23180225000113, co-funded by the European Regional Development Fund (FEDER).

References

[1] A. Hu, A. Li, X. Jin, and D. Zou, “ThermoStereoRT: Thermal Stereo Matching in Real Time via Knowledge Distillation and Attention-Based Refinement,” *Proc. IEEE Int. Conf. Robot. Autom.*, pp. 3766–3772, 2025, doi: 10.1109/ICRA55743.2025.11127815.

[2] Y. Guo, H. Kong, and S. Gu, “Unsupervised Multi-Spectrum Stereo Depth Estimation for All-Day Vision,” *IEEE Transactions on Intelligent Vehicles*, vol. 9, no. 1, pp. 501–511, Jan. 2024, doi: 10.1109/TIV.2023.3331387.

[3] A. Adán, A. López-Rey, and A. Ramón, “Robot for thermal monitoring of buildings,” *Autom. Constr.*, vol. 154, p. 105009, Oct. 2023, doi: 10.1016/J.AUTCON.2023.105009.

[4] Q. Zhang *et al.*, “Thermal-visible stereo matching at night based on Multi-Modal Autoencoder,” *Infrared Phys. Technol.*, vol. 136, p. 105010, Jan. 2024, doi: 10.1016/j.infrared.2023.105010.