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Multi-Modal Point Cloud Registration for Inspection of Industrial Components

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Abstract

Thermography is a Non-Destructive Testing (NDT) technology aimed at non-invasively measuring the thermal distribution of a specimen by quantifying electromagnetic radiation with wavelengths having a lower frequency than the visible light part of the spectrum. Despite some previous studies having addressed the estimation of surface and shape characterization from multiple or single active thermograms [1, 2], thermography by nature is a bi-dimensional sensing technology unable to provide information about the specimen's texture and geometry without any preparatory process. Thus, many studies have recently focused on using multi-modal platforms to obtain extensive information about the scene. This study proposes a method to register consecutive multi-modal point clouds obtained by a novel multi-modal platform containing thermal, visible, and depth sensors. The introduced method uses the acquired point clouds to form a complete 3D model of the inspected industrial component containing thermal and texture information. Moreover, this study conducted some experiments to demonstrate the system's capabilities and to evaluate the registration method's effectiveness.

Keywords Multi-Modal Platform, Point Cloud Registration, Scene Reconstruction, Thermography, Non-Destructive Testing, Remote Sensing.

1. Introduction

Industrial and construction components are periodically subjected to inspection to ensure performance, safety, and structural integrity assessment. Infrared Thermography is a non-destructive and non-contact technique that can detect surface and near-surface defects such as debonding, discontinuity, delamination, and humidity. Thermography inspection is based on the premise that anomalies can alter the heat transfer flow and create a different thermal signature on the inspected surface, where the defects will appear in the thermograms as zones with relevant temperature differences [3].

During recent years, many studies investigated the use of coupled imaging sensors for Non-Destructive Testing (NDT) of industrial and construction components, and infrastructures [4, 5, 6, 7]. Different imaging technologies demonstrate specific but limited physical characteristics of a specimen. For instance, raw thermal images do not present textural and geometrical information of the specimen. However, some studies presented different approaches to estimate the shape of specimens from thermal images to correct distorted thermograms and improve the data interpretation [1, 2]. Thus, the use of a thermal camera coupled with other sensors can provide complementary information about the surface, and subsurface condition of the inspected component [8], including but not limited to remote and drone-based inspections. Javidi et al. proposed a multi-modal system for detection and characterization of road cracks to overcome challenges caused by shadows, oil spills, and other distress [6]. Lee et al. investigated the use of thermal and visible cameras together for solar panel inspection [7]. They used visible images to detect the panels and thermal images to identify affected panels. Likewise, Nouah et al. combined visible and infrared images to estimate the local orientation of specimen surface and overcome the difficulties on the inspection of non-planar components [9].

Inspectors often acquire data from different fields of view (FOVs) to cover all aspects of a specimen during a data session, especially when inspecting large or mid-sized components. Thus, analyzing and visualizing the acquired data from different FOVs can be challenging. Also, the localization and reporting of detected defects with respect to the specimen geometry requires much effort and pre-inspection considerations. 3D presentations of infrastructures are already extensively used in different industries like construction, mining, power transmission, helping bridge the gap between computer-aided BIM designs and the real world [10, 11], and critical operation planning [12]. Ham & Golparvar-Fard presented a method to employ 3D spatio-thermal modeling for visualizing the actual thermal resistance and condensation problems in building inspections [13]. Nakagawa et al. introduce a method for visualizing thermal variations on a 3D model of the observed scene by coupling a thermal and stereo depth camera [14].

The detection and characterization of defects requires extensive information about the texture and geometry of the area of interest in many scenarios. For instance, inspectors can use the combination of thermal and visible images to determine whether the identified abnormality is caused by a subsurface defect or an attached object to the surface. Also, geometric

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information can assist the inspectors in determining the size and location of the affected area. Therefore, an approach to localize the defects on a reconstructed 3D model of the specimen can assist inspectors during the analysis and companies in their decision-making process for possible maintenance. Akhloufi & Verney presented a multi-modal framework for non-destructive inspection [15] using 3D and thermal sensors. Narváez et al. employed LiDAR and thermal sensors to provide a 3D thermal reconstruction of crops for analyzing their thermal and geometrical characterisation [16].

This study presents a method to register consecutive multi-modal point clouds acquired by a platform designed in the MiViM laboratory of Université Laval. The platform acquires multi-modal data containing aligned thermal, texture, and depth information. This study uses the obtained data from different fields of view to form a thermographic 3D model of a component. The provided model can be used for analyzing and visualizing the specimen. This study employs a technique to remove the outliers caused by the sensor error or environmental conditions, based on the analysis of local density as part of preprocessing steps to prepare the individual point clouds for the registration process. Later, a global registration approach aligns the consecutive point clouds to initialize the Iterative Closest Point (ICP) method for final registration. Additionally, the study introduces an approach for fusing thermal values collected from different FOVs of a specific area of interest. This study conducts multiple experiments to investigate the presented method's efficiency and performance and demonstrate its applications in real case scenarios.

2. Registration of Multi-Modal Point Cloud

The methodology consist of registering consecutive point clouds acquired by a multi-sensor system that can be used as hand-help or drone-based platform. The developed platform includes thermal, visible, and depth sensors connected to an embedded system used to collect, transmit and store the acquired data. The platform uses a novel calibration board before data acquisition to measure the camera parameters and align the modalities of interest. Also, it employs a data fusion technique to generate point clouds containing color and temperature values based on the aligned modalities. The obtained point clouds provide 3D models of the scene based on the temporal cameras' FOVs.

The problem of multi-viewpoint same-source point cloud registration can be formulated as follows. Given a collection of N overlapping point clouds $S_i \in \mathrm{R}^3, i = \{1..N\}$, the registration process consists of deriving a rigid or non-rigid set of transformations $T_i \in \mathcal{T}$, where $\mathcal{T}$ represents the set of all possible transformations, such that the collection of point clouds $\mathcal{S}$ is optimally aligned in respect to a distance measure $\text{dist}(x, y)$.

$$T_i^{'} = \underset{T_i \in \mathcal{T}}{\arg\min}\ \text{dist}(T_i(S_i), S_j) \tag{1}$$

However, in the case of multi-modal point clouds, not only the spatial aspect of the points must be aligned, but the other sensors' information must also be transformed. For example, in this case, the thermal patterns and variations observed in different FOVs have to be consistent in the registered model. To do so, a method for the fusion of multiple thermal values in overlapped points should be used.

In this study, the presented method processes the consecutive point clouds to form a complete thermographic 3D model of the scene. The first step of the presented method is to remove outliers in the obtained point clouds to ensure the quality of resulting point cloud data. This study uses a method based on local density analysis to identify and remove outliers. Next, the consecutive point clouds were aligned using a global registration approach. Since the global registration methods do not align the point clouds tightly, an Iterative Closest Point (ICP) method enhances the registration results.

The experiments were conducted for multiple scenarios using a passive thermography approach in order to assess the efficiency and performance of the proposed method and demonstrate its applications in real case scenarios. Figure 1 demonstrates the sample point cloud from an insulated pipeline under laboratory conditions.

Fig. 1. *Sample point cloud collected by the platform from an insulated pipeline under laboratory conditions. The figure shows the point cloud with thermal and visible values.*

3. Conclusion

In this paper, a method to register consecutive multi-modal point clouds has been presented. The experiments used a novel multi-modal platform containing thermal, visible, and depth sensor to inspect multiple industrial components. The results were investigated regarding the generation of thermal 3D models, specifically concerning outliers removal, point cloud registration, and fusion of thermal values acquired from different FOVs. Therefore, the findings can contribute to the field of industrial inspection by advancing the generation of multi-modal 3D models, which can provide different types of information to be used for advanced visualization and analysis of operating components.

References

[1] Emmanuel Barker, Xavier P. Maldague, and Denis Laurendeau. Shape reconstruction from a single thermal image. *Optical Engineering*, 34(1):154 – 159, 1995.

[2] Jean-Francois Pelletier and Xavier P. Maldague. Shape from heating: a two-dimensional approach for shape extraction in infrared images. *Optical Engineering*, 36(2):370 – 375, 1997.

[3] Xavier PV Maldague. *Nondestructive evaluation of materials by infrared thermography*. Springer Science & Business Media, 2012.

[4] Prabhjot Singh, Yanyan Wu, Robert Kaucic, Jiaqin Chen, and Francis Little. Multimodal industrial inspection and analysis. 2007.

[5] Tsz Hei Heison Chan. Real-time multi-sensory monitoring by automated routing of uav in civil/building construction site and cavern development: to improve safety, health and productivity. 2017.

[6] Bahram Javidi, Daesuk Kim, and Sherif El-Sayed Kishk. A laser-based 3d data acquisition system for the analysis of pavement distress and roughness. Technical report, Connecticut Transportation Institute, School of Engineering, University of Connecticut, 2004.

[7] Sung Won Lee, Kwang Eun An, Byung Don Jeon, Kyoung Yeon Cho, Seung Jae Lee, and Dongmahn Seo. Detecting faulty solar panels based on thermal image processing. In *2018 IEEE International Conference on Consumer Electronics, ICCE 2018*, volume 2018-Janua, pages 1–2. IEEE, 2018.

[8] Imed Riadh Farah, Wadii Boulila, Karim Saheb Ettabaa, and Mohamed Ben Ahmed. Multiapproach system based on fusion of multispectral images for land-cover classification. *IEEE Transactions on Geoscience and Remote Sensing*, 46(12):4153–4161, 2008.

[9] Ahmed Nouah, Xavier Maldague, and François Robitaille. Shape correction in transient thermography inspection of non-planar components. In *Proc. Quantitative Infrared Thermography, Eurotherm Seminar*, volume 27, pages 224–228, 1992.

[10] Jyun-Yuan Chen, Chao-Hung Lin, Po-Chi Hsu, and Chung-Hao Chen. Point cloud encoding for 3d building model retrieval. *IEEE Transactions on Multimedia*, 16(2):337–345, 2014.

[11] Frédéric Bosché, Mahmoud Ahmed, Yelda Turkan, Carl T. Haas, and Ralph Haas. The value of integrating scan-to-bim and scan-vs-bim techniques for construction monitoring using laser scanning and bim: The case of cylindrical mep components. *Automation in Construction*, 49:201–213, 2015.

[12] Xiaoshui Huang, Guofeng Mei, Jian Zhang, and Rana Abbas. A comprehensive survey on point cloud registration, 2021.

[13] Youngjib Ham and Mani Golparvar-Fard. 3d visualization of thermal resistance and condensation problems using infrared thermography for building energy diagnostics. *Visualization in Engineering*, 2(1):1–15, 2014.

[14] Wataru Nakagawa, Kazuki Matsumoto, Francois de Sorbier, Maki Sugimoto, Hideo Saito, Shuji Senda, Takashi Shibata, and Akihiko Iketani. Visualization of temperature change using rgb-d camera and thermal camera. In *European Conference on Computer Vision*, pages 386–400. Springer, 2014.

[15] Moulay A Akhloufi and Benjamin Verney. Multimodal registration and fusion for 3d thermal imaging. *Mathematical problems in engineering*, 2015, 2015.

[16] Francisco J Yandún Narváez, Jaime Salvo del Pedregal, Pablo A Prieto, Miguel Torres-Torriti, and Fernando A Auat Cheein. Lidar and thermal images fusion for ground-based 3d characterisation of fruit trees. *Biosystems Engineering*, 151:479–494, 2016.