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Use of Camera and AI for Mapping Monitoring for Architecture

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Abstract
This research focuses on studying low-cost techniques for rapid mapping, utilizing sensors equipped on smartphones. These devices were installed on a radio-controlled vehicle to conduct an experimental campaign aimed at evaluating the performance of LiDAR sensor. By collecting data, machine learning algorithms were employed for the detection of architectural defects.

Keywords Cultural heritage · Damage detection · Low-cost sensors · Dynamic acquisition · Convolutional neural networks

Introduction

This study falls within the disciplines of relief and applied mechanics. It presents the preliminary results of an experimental campaign, still ongoing, which wants to explore in detail the *reality-based* investigation methodologies using low-cost tools and technologies coupled with detection techniques.

Specifically, the research analyzes the potential of miniaturized sensors, of subcentimeter size, such as LiDAR and cameras integrated into Apple products, with a particular interest in last-generation smartphones and tablets. These technological devices present several advantages of undoubted interest for forecast monitoring and rapid-mapping relief disciplines applications. Therefore, a series of tests were carried out to evaluate the potentiality of these sensors for dynamic acquisitions. More in detail, the performance of the sensors mounted on the iPhone12Pro and

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iPhone12ProMax have been analyzed. These smartphones have been mounted, with 3D-printed supports, on a radio-controlled vehicle. The collected data with the proposed instrumented vehicle has become the starting dataset to develop a detection algorithm, based on artificial intelligence and machine learning.

The Research

In the last decades, the Cultural Heritage sector is an experimental field in which a lot of new techniques and methodologies were adopted for digital three-dimensional relief. In this vision, the innovative survey tools have deeply transformed the procedures for data acquisition, elaboration, and management. The adoption of a wide range of sensors and algorithms allowed significant progress, reducing work times and instrumentation costs. At the same time, the recent technological upgrades permitted the miniaturization of increasingly performing sensors able to acquire three-dimensional and colorimetric data, giving the possibility to develop new strategies for architectural monitoring. In particular, these improvements allow seeing new opportunities in the diagnostic and monitoring precinct in which continuous acquisitions and rapid mapping are required (Fassmeyer et al. 2021).

Starting from these premises, the proposed research focused on analyzing LiDAR (Light Detection and Ranging sensor) and Camera sensors as reliable instruments for rapid mapping and data acquisition. To evaluate the performance of these sensors and the potential of this technology, a preliminary test campaign was conducted at the Architecture Department of the University of Naples Federico II. To properly assess the sensor's performance and potential, 3D data was acquired dynamically by installing smartphones on a radio-controlled vehicle. This approach allowed for a more accurate evaluation of the sensor's capabilities in a practical and dynamic setting.

To address the research questions, the activities were organized into several steps: (1) analysis of the instruments used; (2) acquisition of 3D point clouds, camera frames, and vehicle data; (3) pre-processing of the data; (4) analysis of various types of neural networks; (5) preparation of the training database; (6) training and validation of the convolutional neural network; and (7) further validation of the global detection procedure on other acquired data (Fig. 1). In the first phase of the presented workflow, the main characteristics of the two sensors

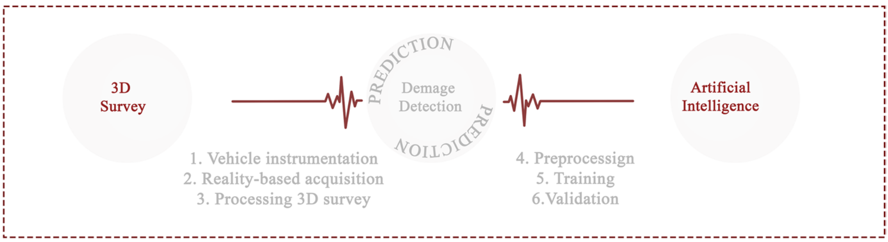

Fig. 1 Methodological approach of the research

and the radio-controlled vehicle were evaluated. Since 2020, the LiDAR which is now integrated into several last-generation smartphones and tablets, uses *Vertical Cavity Surface Emitting Lasers* (VCSEL) for laser signal emission and *Single Photon Avalanche Diodes* (SPAD) sensors for receiving the reflected signal, with a maximum declared range of 5 m. Although this sensor is primarily intended for augmented reality applications, some functional studies have already been conducted and documented in the literature that apply it to three-dimensional reliefs (Falcone and Campi 2021; Spreafico et al. 2021; Fiorini 2022; Teppati et al. 2022).

Unlike other cited studies, this work involved acquiring data on a motorized vehicle at three different velocity levels: low, medium, and high. To ensure the smartphones were securely installed on the vehicle and to prevent them from touching each other during data acquisition, a 3D-printed support with a boomerang shape was created. In addition, a third smartphone with an Android operating system and a dedicated application was installed to measure the vehicle's velocity. The reference radio-controlled vehicle used was a 4WD Destructor BBR Buggy brushed RTR, at a scale of 1:8, with its main characteristics depicted in Fig. 2.

After evaluating the technological characteristics of the instruments, the next step is the data acquisition phase, which is further divided into two sub-steps. Data collection in the scenario, which consisted of architectural models at a scale of 1:100, was organized into two macro-acquisitions. The first acquisition involved acquiring "clean data," while the second sub-phase involved acquiring “dirty data” with colored stickers applied to simulate degradation phenomena on the models.

In both phases, morphometric and colorimetric information was simultaneously acquired on the two devices using the “3D Scanner” application. This allowed for the real-time visualization of point clouds, as well as customization of recording mode settings and cloud quality. A total of 26 scans were acquired (13 on the iPhone 12 Pro and 13 on the iPhone 12 Pro Max), each lasting 30 s. These scans varied in terms of vehicle velocity during acquisition (low, medium, and high) and point cloud quality (low or high).

The use of colored stickers on the models helped to simulate real-world degradation phenomena and allowed for the acquisition of “dirty data,” which is often encountered in practical applications. The use of the “3D Scanner”

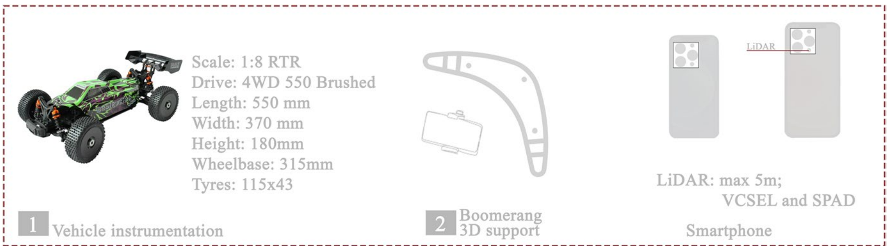

Fig. 2 Tools used

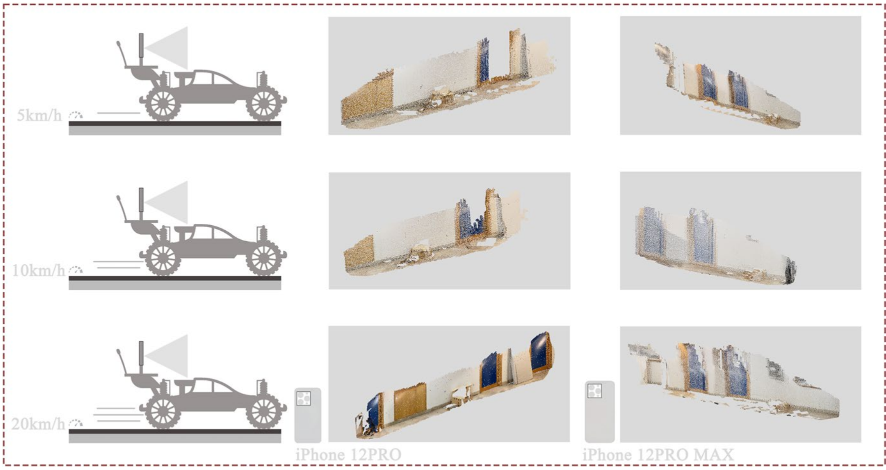

Fig. 3 Data acquisition with the radio-controlled vehicle and iPhone 12PRO and iPhone 12PROMAX

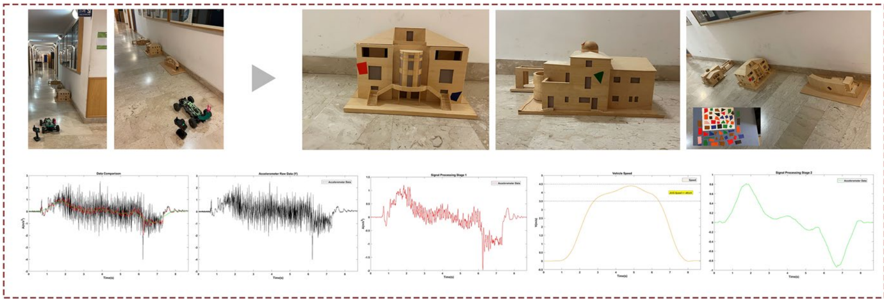

Fig. 4 Acquisition scenario and vehicle dynamics signals analysis

application enabled the acquisition of both morphometric and colorimetric data, which is crucial for developing a comprehensive understanding of the scenarios being studied. The acquisition of a range of scans at varying velocities and qualities helps to create a more comprehensive dataset for subsequent analysis.

It should be noted that all scans were processed within the application itself, which required 5 GB of storage space and significantly reduced the battery charge due to high computational cost. The processing time for each scan was approximately 3 min, including 1 min for coloring. The resulting data were exported in. ply format using the CloudCompare application.

First, a density analysis of the acquired point clouds, from the different devices, has been carried out, comparing the results for the different vehicle velocities and the set quality. The results, for both devices, are significant: the point clouds density analysis showed a much higher amount of acquired points for the acquisitions obtained with high velocity and high quality. For what concerns the coloring data, it is possible to see how the quality of the integrated sensors of the iPhone 12Pro Max is significantly higher if compared with the other smartphone (Figs. 3, 4).

Although the different commercial applications suggest, during the registration phases, to maintain a distance from the object to detect between 1 and 4.5 m and that fast movement could negatively influence the quality of the results, after our analysis, it is possible to state that the sensor has an effective range that does not exceed the 4.30 m but it can acquire data up to 40 km/h.

After that, a series of different Neural Networks have been analyzed to develop a robust detection procedure. The choice of the author fell on a Convolutional Neural Network (CNN) (O'Shea and Nash 2015; Albawi et al. 2017), commonly used for different purposes related to object detection starting from images and/or point clouds dataset (Zhang et al. 2016; Kagaya et al. 2014; Yamashita et al. 2018). The main advantage of this technique is that, after a proper pre-processing of the database of the image, including an augmentation and labeling phase, the network is able to detect automatically the relevant features on which to calibrate the detection procedure.

Then, various training and validation tests were conducted to optimize the network's hyperparameters and maximize detection performance. Finally, a validation was performed on another portion of the collected data, which included both clean and dirty architectural models, to assess the reliability of the methodology. Despite the inherent limitations of the sensors used for data acquisition, the results are promising and warrant further research to expand the application to more complex scenarios.

Conclusion

In conclusion, based on the various tests conducted in this experimental campaign, it is evident that the presented methodology has the potential to significantly enhance traditional forecast monitoring activities. The combination of LiDAR, camera and detection algorithms could serve as a crucial tool, if investments in this technology continue at the same pace as in recent years. Additionally, the ability to obtain relevant information about vehicle conditions during data acquisition could be a key factor in real-world scenarios. Now, the instrumentation still shows some limits related to the maximum distance range of the detectable objects, but the quality of the obtained results is encouraging to extend the proposed methodology to larger-scale contexts.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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