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Joint use of GPR, IRT and TLS techniques for the integral damage detection in paving

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HIGHLIGHTS

- Three NDT with different principles, to the detection of damage in paving.
- The union of the different data implies integral knowledge of the paving materials.
- Fault identification by the combined interpretation of inner and superficial data.
- Results validate the application of each technique for damage detection.
- Individual techniques are reinforced, the combination does not nullify single use.

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ABSTRACT

In order to preserve the condition of infrastructure and guarantee its usability, the availability of inspection techniques is essential, provided these are able to determine the condition of the infrastructure causing minimum disturbance and post-inspection consequences. Non-destructive techniques present characteristics to reach all these requisites, especially regarding time minimization. With the objective of reaching maximum data extent and accuracy, this paper proposes the joint use and interpretation of three techniques: ground-penetrating radar (GPR) for the detection of inner pathologies, infrared thermography (IRT) for the evaluation of the state of the subsurface of the structure, and terrestrial laser scanning (TLS) for the accurate measurement of geometry and detection of external defects. Each technique acquires data of different nature and different parts of the infrastructure, in such way that their interpretation in an integrated way allows for the accurate detection of superficial and inner pathologies, as well as their location and measurement of dimensions. The joint application of the techniques mentioned has been tested in a road next to the sea, composed by different fill materials placed in order to increase the extent of land towards the water, and deteriorated by the use and the erosion provoked by seawater.

1. Introduction

The performance of road maintenance tasks is essential for the conservation of transport infrastructures, towards the detection and remediation of existing pathologies, both superficial and internal, since both cases can provoke the collapse of the infrastructure and the consequent interruption of its use. The presence of pathologies should be minimized from the roll-out of the infrastructures and during all their life cycle. Different techniques are currently used for the detection of pathologies in infrastructure, each adequate for a specific pathology. Superficial pathologies are commonly visible, in such way that a visual inspection allows for its detection, and direct measurements in situ give information about its size and depth, indicators of their severity. The detection of internal pathologies has not been directly solved, being the most common procedure the achievement of punctual information of interior layers of the infrastructure through core drilling of the road.

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In order to eliminate the need for core drilling, this paper presents a methodology for the integral inspection of infrastructures, which is composed by a combination of non-destructive testing (NDT) techniques: (1) ground-penetrating radar is applied for the detection of pathologies in the inner layers of the road, such as cracks in the wearing course, buried holes and settlement problems; (2) infrared thermography is used for the evaluation of the condition of the subsuperficial and superficial layers, with a depth of 2–5 cm; and (3) laser scanning acquires 3D topographic data of any object surface from where geometric information is derived, including the superficial pathologies.

Ground-penetrating radar (GPR) has been established as one of the most recommended NDT for routine subsurface inspections, which has proven its suitability for providing high quality images of the radar signal in the interior of the structures. GPR is a prospecting method based on the propagation of electromagnetic pulses in very short time. The radar-wave travels from the antenna through the medium and is reflected when encountering an interface between two different media with different dielectric constants. The likelihood of detecting targets is greater when the contrast between dielectric properties of the target and the background increases, which can affect the resolution and accuracy of the method. Numerous studies have been published about the application of GPR to many aspects related to civil engineering field [1]. Regarding its use for road infrastructure quality management and detection, there are successful works in pavement inspection [2], bridges inspection [3] and tunnel evaluation [4]. Published works also deal with GPR applied for assessing moisture [5], rebar corrosion [6], and detection of subsurface defects such as cracking, voids and delamination [7–10].

Infrared thermography (IRT) is a non-destructive technique that allows the calculation of the temperature of objects based on the measurement of the radiation emitted in the thermal infrared band of the spectrum (8–14 μm). Thus, the thermographic method relies on thermodynamics phenomena, and heat transfer events to detect superficial or subsuperficial anomalies in bodies [11]. In this way, the thermophysical properties and/or thermal response of objects changes in the areas where an anomaly is present (internal and external cracks, air cameras), in such a way that their response to thermal stimuli, both natural from the Sun and artificial, both processed directly or with active thermography methods [12–14], is different with respect to undamaged areas. In addition, given the superficial nature of the technique, the emissivity of the surface of the objects presents great influence on the thermographic results [15]. Thus, in addition to the material, its surface appearance, such as roughness, rusting level, presence of cracks and dents, affect the emissivity of the objects, influencing the apparent temperature measured by the camera. Infrared thermography has been rarely applied in road inspection, a few approaches have been found in literature regarding bridges [16], road surfaces [17] and asphalt pavement [18,19].

Terrestrial laser scanning (TLS) accurately records 3D topographic data of real-world objects or environment using point clouds. The resulting point cloud is a high-resolution dataset with x, y, z coordinates of the scanned scene, consisting of point attributes such as reflected intensity value (i) for each point, and their RGB data obtained from cameras, mapped to the coordinates. This technology has been widely applied in geometric surveys [20], structural health monitoring [21], structural assessment [22], deformation measurements [23], pavement evaluation [24] and cracking [25].

The joint application of these techniques has been proved as an adequate solution for the maximization of data acquired and available in the analysis of construction materials. For example, IRT data have been fused with TLS data, as a point attribute, for the three-dimensional detection of pathologies in buildings [26–28]. An introduction to the combination of IRT with geophysical techniques can be found in [29], where IRT, ultrasounds and electric geophysical methods are applied for the detection of internal defects in masonry structures, such as wall tiles and other building materials. Within the geophysical methods, GPR has also been applied in conjunction with IRT to inspect archaeological sites [30,31], as well as to detect cracks and voids in asphalt [32]. Integral TLS and GPR approaches have been applied to analyze masonry arch bridges; in which the TLS data were used to generate 3D models (external geometry), while the GPR data provided inner parameters such as ring-stone thicknesses [33,34]. Moreover, GPR has been used in combination with mobile LiDAR for measuring pavement layer thicknesses and volumes [35]. Last, the combination of IRT and GPR data with the 3D model provided by TLS has been applied for the detection of water channels and moisture source in masonry bridges [36].

2. Materials and methods

2.1. Background of the survey area

An area chosen as a case study is an esplanade formed by heterogeneous port filling, raised from sea level through the contribution with "all-one" material (Fig. 1a). Compacting of the materials has been performed with traditional mechanical procedures consisting of heavy successive coatings of 0.5–1 m thick.

The filling surface is covered by paving blocks fixed by mortar and grout (Fig. 1b), following the process of traditional construction, which dates from the years 1930–1940s. From that time, partial layers of bituminous material have been poured on the paving to reduce the effect of erosion and cover existing cracks, holes, and other types of deteriorations, and improve vehicle rolling. In fact, nowadays, the surface alternates patches of bituminous layers with others of rigid concrete roads (Fig. 1c). In addition, there are evidences of punctual maintenance operations using low-quality arid materials, such as shell mashes (Fig. 1d).

This area is currently destined for parking and vehicle transit, and is affected by different pathologies: the greatest problems are caused by subsidence and partial sinking, but also by numerous cracking in the bituminous surface and in the concrete patches (Fig. 1e). Consequently, the cover (and protection) of the paving blocks has disappeared.

In this work, an area of approximately 192.5 m^2 was covered from the parking to the edge of the quay with a cross-section of 7 m width and 27.5 m long. For an exhaustive evaluation, the data acquisition was based on 3D methodologies by using three different NDT techniques, namely, GPR, IRT and TLS (Fig. 2).

2.2. Ground-penetrating radar

The GPR survey was conducted using a RAMAC system from MALÅ Geosciences (Fig. 2a) with a CUII control unit and two, 800 MHz and 500 MHz, antennas mounted on a survey cart with an odometer wheel as triggering system. The data acquisition was based on single antenna 3D GPR methodologies using the common-offset mode with the polarization perpendicular to the data collection direction, and the acquisition parameters were 2 cm trace-interval and time window of 60 ns and 75 ns for the 800 MHz and 500 MHz antennas, respectively. To cover the entire grid, parallel 2D profiles were collected at regular intervals of 10 cm spacing resulting in a total of 67 profiles. Two measurement tapes were placed on the opposite parallel sides of the grid for measuring the cross track spacing and a string was used as a guideline to move the survey cart in order to ensure straight profiles. Moreover, the four corners of the grid were georeferenced by the terrestrial laser scanner to accurately position the profiles.

All the collected profiles were filtered before interpretation to correct the down shifting of the signal caused by the air-ground interface and to amplify the received signal, as well as to reduce clutter and unwanted noise in the raw data. The objective of filtering was to enhance the extraction of information from the received signals and to produce a subsurface image including all features of interest, which simplifies the interpretation of the GPR data. The data were processed with the ReflexW software [37]. Table 1 shows the filters and parameters used to process both 800 and 500 MHz data. Once the 2D data were processed, these data were exported to the 3D-data-interpretation module of the same processing software for the 3D cube creation. In addition to the equidistant profile increment, all the radargrams acquired with each antenna frequency were registered with equal trace-distance and time increment (number of samples in which the time window is divided), so the cube was generated without interpolation. This 3D-data allow for the extraction of either parallel or crossing 2D-lines in order to enhance the spatial correlations of the filling layers and possible damages in depth.

To transform the travel-time distance (ns)axis of the GPR image into a depth/distance (m) axis, the radar-wave velocity was previously calibrated in different positions of the esplanade since this parameter is very dependent on fill material