NDT sensor fusion in structural pavement condition surveys

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ABSTRACT

The EU FP7 RPB HealTec project presents the concept of fusion of infrared thermography (IRT), ground penetrating radar (GPR) and air-coupled ultrasound (ACU) in structural pavement condition surveys. The traffic speed data collection ensures an optimal road inspection procedure, while the combination of the selected multidimensional Non-Destructive Testing (NDT) techniques extends the information content normally produced by individual sensor systems. Specifically, GPR and ACU provide in-depth measurement of the pavement structure characteristics, while IRT covers the entire road lane and identifies changes in the segregation patterns of the surface asphalt layer. Following the synchronized acquisition and automated processing of the individual sensor data streams, sensor fusion is performed at the decision level. The processing methods are based on trend deviation detection, thus ensuring that all significant changes in the pavement condition including surface/subsurface defects and layer structure variations are identified. The locations of the detected deviations are marked with 'alarm flags' and mapped along the survey route. The decision support output is presented for further analysis by an operator.

INTRODUCTION

The European Road Network (ERN), which is estimated at approximately 5,000,000 km, is undoubtedly one of the most important land infrastructures in the EU, both in economic and social terms. However, the most important factor for the quality of the ERN is maintenance, which is considered to be the most expensive function of a highway operating agency. The annual total cost of road construction and maintenance is measured in tens of billions of euros (EC, 2016). As a result, there is a strong need for an early detection of pavement deterioration mechanisms and potential presence of defects through optimization of the road infrastructure inspection technologies.

As shown in Figure 1, well-timed preventive maintenance actions such as crack sealing, surface coating, or patching extend the road pavement lifetime by deceleration of the deterioration processes before rehabilitation or reconstruction work is required. Further, maintenance improves pavement serviceability (Christopher, 2006). Accordingly, regular road condition surveys for detection of defects potentially causing pavement deterioration reduce the costs of maintenance, the costs due to impedance of goods travel during maintenance periods, and the costs related to traffic accidents. The pavement condition is characterized with respect to the functional and structural aspects. The structural condition determines the structural capacity of the pavement from the measured layer thickness, structural changes, and material properties.

In general, because of the varying and constantly changing international standards of pavement design and rehabilitation procedures, as well as the limitations related to the vast amounts of data, development

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of the universal survey guidelines or tools is a complex task. And although there is a number of commercial off-the-shelf survey equipment systems successfully utilized in the highway community such as GPR for layer thickness profiling and falling weight deflectometers (GSSI, 2016), laser profilometers for texture analysis (Fugro Roadware, 2016), etc., there is a need for further optimization and development of NDT sensor-based systems that cover wider set of features of the structural pavement condition.

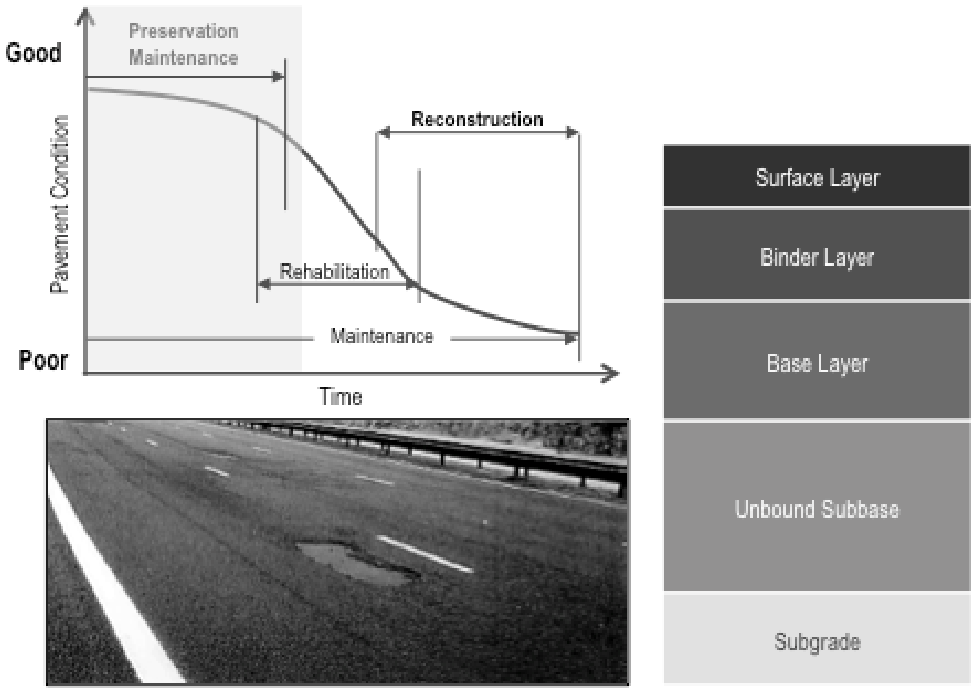

Figure 1. Flexible pavement life cycle and general layer structure

The ultimate goal of the FP7 EU RPB HealTec project (RPB HealTec, 2016) is to upgrade and optimize the current survey procedures for the assessment of the pavement structural condition. This should assist decision making related to increasing the life expectancy of road infrastructure and help reduce the cost of future construction and maintenance to the European road network.

The design of RPB HealTec system is based on integration of multiple NDT sensors in order to provide the maximum coverage of pavement structural condition and enable fast road inspection at traffic speeds. The sensor integration improves the performance of any individual sensors. The corresponding identified optimal set of sensors includes ground penetrating radar (GPR), infrared thermography (IRT), and air-coupled ultrasound (ACU). While GPR has been widely employed in road surveys for many years (GSSI, 2016; Heitzman, 2013; CATSURVEYS, 2016) and constitutes the basis for the proposed integrated solution, the application of IRT and ultrasound in pavement surveys has considerable novelty. There are only few examples of the implemented IRT systems (FLIR, 2016; Heitzman, 2013; Penetradar Corporation, 2016) with IRT being used specifically in bridge deck inspection (NEXCO-West USA, 2016).

RPB HEALTEC SYSTEM

The developed RPB HealTec system is an automated and integrated NDT solution for traffic speed assessment of road pavement/bridge deck structural condition. Integration of GPR, IRT and ACU techniques provides multi-dimensional information of the pavement condition with high level coverage for detection of surface and subsurface defects, structural and material changes and deterioration regions. The system is optimized for operation at 40-60 km/h speed thus eliminating substantial disruptions to traffic for inspection of long sections of highways.

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Based on the analysis of thermal segregation patterns, the high-resolution IRT camera is employed for inspection of the structural condition of the top asphalt layers. This includes detection of surface defects and shallow subsurface delaminations as well as deviations in the asphalt material properties (e.g., density, trapped moisture) and changes in structure. The employed uncooled FLIR A655sc IRT camera model has high sampling rate and was select as optimal for high-speed surveys.

The SIR-30 GSSI GPR control unit with an array of low and high frequency GPR antennas (0.9 and 1.6 GHz) provides information on the pavement structure ensuring coverage of all subsurface layers. Installed on a specially designed trolley, the GPR module is optimized for high-speed inspection for detection of subsurface defects such as delaminations between the layers, voids, material deterioration regions and deep cracks, changes in the pavement structural design. Furthermore, the use of ACU system with DR.HILLGER AirTech system (DR.HILLGER, 2016) with low frequency 75 kHz transducers is applied for sensitive profiling of the surface layer condition and identification of the variations in the asphalt density.

The GNSS/INS navigation systems and HD video are employed for high accuracy spatial mapping and referencing of the detected defect locations. All NDT modules are mounted on a trolley or camera holders, correspondingly, (Figure 2) that can be straightforwardly installed on a survey vehicle along with the other hardware components. On the software integration level, synchronization of the sensor data (which is a prerequisite for sensor fusion) is based on the timestamp recording and distance trigger pulses from a distance measuring instrument (DMI). The data acquisition software is designed to provide functionality for synchronized collection and storage of spatially referenced sensor data.

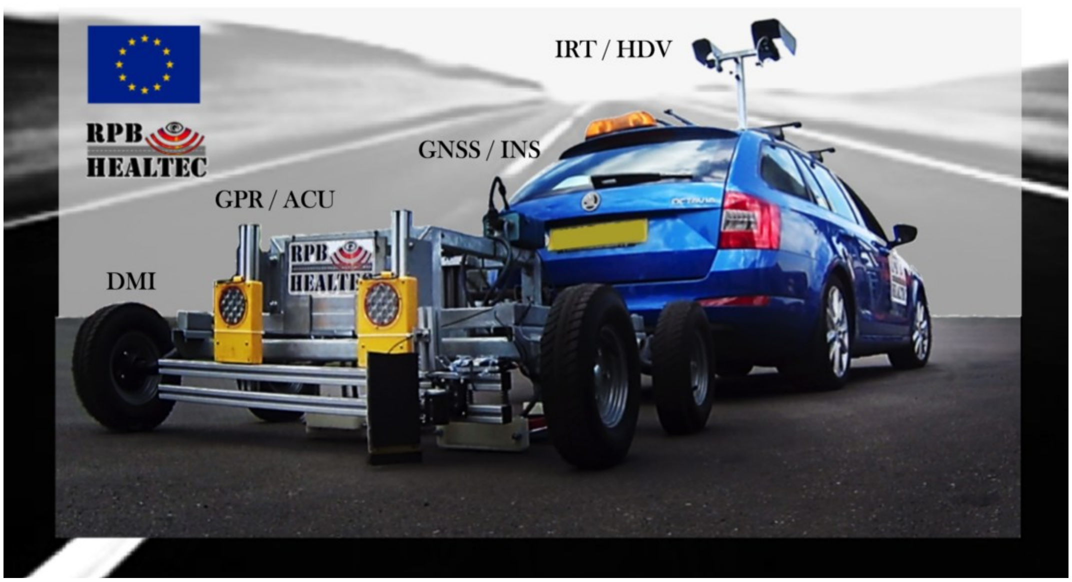

Figure 2. Components of the RPB HealTec system for NDT pavement structural condition surveys

Figure 3 demonstrates an example of the sensor data acquired during a survey including low and high frequency GPR B-Scans, ACU B-Scan, IRT and HDV frames and GIS-mapped GNSS survey route.

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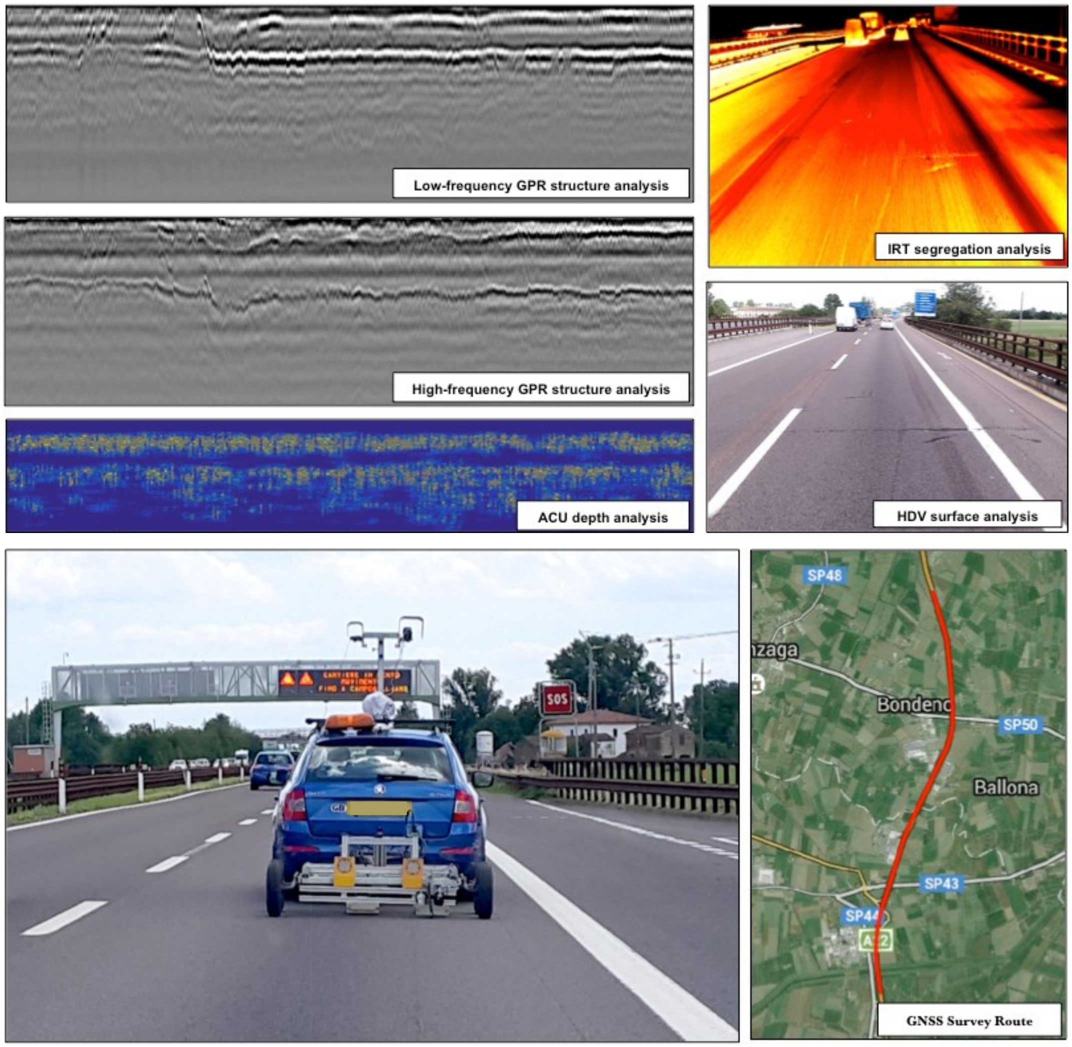

Figure 3. NDT sensor data acquired during a road survey

DECISION LEVEL SENSOR FUSION

Following data acquisition, the sensor data are exported into the RPB HealTec post-processing software for analysis. The corresponding methodology involves automated processing of the individual sensor data streams for detection of critical deviations in the pavement subsurface features together with the extraction of layer thickness profile from the low and high frequency GPR scans.

In IRT data stream processing, an inverse projection transformation and extraction of a region of the pavement surface (e.g., 2.5 by 3.5 m size) is applied to every frame. Next, background removal and multi-threshold adaptive segmentation are used for detection of local critical changes in pavement segregation. In addition, morphological dilation is used for analysis of global changes in the thermal patterns. The GPR and ACU B-scans are split into segments (e.g., 75 m length) and analyzed based on the trend deviation analysis method, which automatically detects all deviations from the uniform layer structure considered to be “significant” and possibly indicating the presence of defects and changes in pavement structure. Spatial registration of multi-dimensional sensor data is based on the timestamp, GNSS reference point and the sensor positioning offset information. The sensor fusion is performed at the decision level with respect to the presence of the detected deviations in surface and subsurface condition and visualization of the processed IRT frames along with the GPR defect mask mapped on the 2D reformatted road lane surface extracted form HDV (RPB HealTec, 2016). The report for an inspected road section includes the

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processed sensor data and the "defect mask" sensor fusion output together with the extracted global IRT segregation patterns and pavement structure profile. This decision-support information can be further used for the evaluation of the defect severity and extent and general assessment of the road quality condition (Figures 4-5) required in the pavement maintenance planning.

The analysis of the sensor fusion results for the data acquired during the field trials on the A22 Motorway (RPB HealTec, 2016) in Italy showed that the combination of the sensor outputs (GPR and IRT, especially) provides significantly more information of the road pavement subsurface condition than the individual sensors. In other words, these NDT sensors are complementary yet reinforce each other when a defect is present. For instance, Figure 4 shows an example of the sensor fusion output at the location of the transition between a bridge deck and pavement with the presence of multiple cracks, which were detected in all sensor data streams. Moreover, the cross-referencing of the multi-dimensional sensor outputs should be used for verification of the "existence" of the detected defects in order to decrease the number of false positive alarms. For instance, while the GPR analysis is efficient for detection of subsurface defects such as delaminations between the layers and material/structural changes, IRT provides the segregation map for the entire lane thus allowing assessment of the condition of the regions not covered by the GPR antennas. IRT also visualizes the pavement surface condition around the detected defects. The corresponding examples include delaminations close to the lane borderline, deteriorated joint in the middle of the lane, structural changes (e.g., patching and overlays), local variations in the material properties (e.g., trapped moisture, asphalt degradation), surface defects (e.g., cracking, potholes), etc. In Figure 5, the deteriorated region with subsurface delamination is detected in both GRP and IRT data, while the mud pumping defect and the pavement joint with trapped moisture also can be also seen on the reformatted IRT frame. Furthermore, it has to be noted that, in comparison to HDV, IRT is highly efficient in detection of surface defects by providing information on the extent and boundaries of the deteriorated region, particularly in the case when the granular texture of porous asphalt masks minor defects.

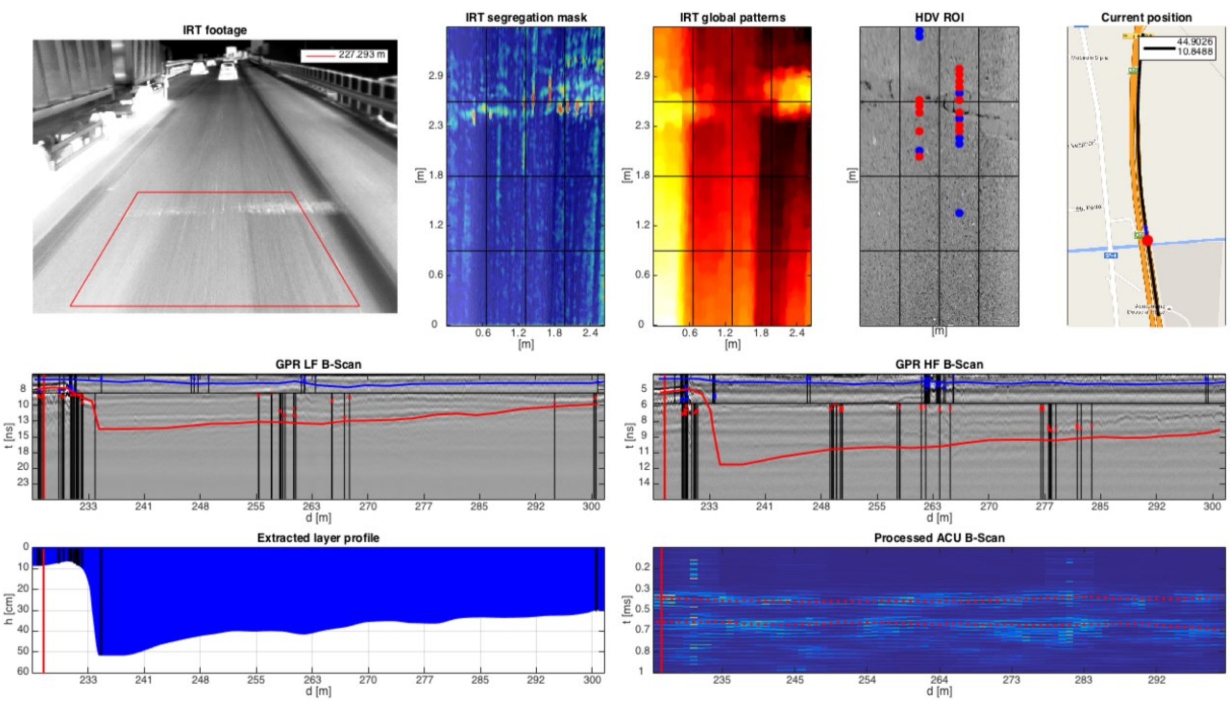

Figure 4. Decision level sensor fusion example: transverse crack and change in pavement structure

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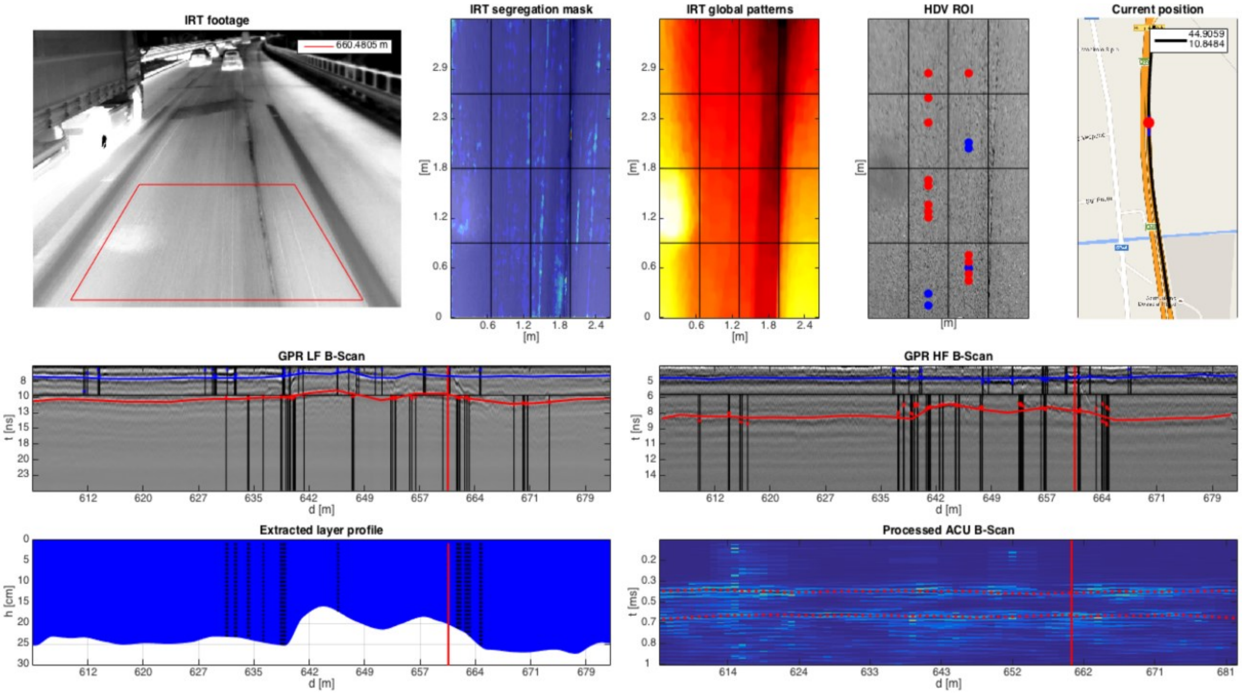

Figure 5. Decision level sensor fusion example: subsurface delamination

SUMMARY

The testing results of the RPB HealTec integrated NDT system demonstrate that the fusion of multi-dimensional NDT sensors provides significantly more information on the road pavement subsurface condition than the individual sensors, thus increasing the validity of the survey results. In summary, while GPR remains the principal technique in pavement surveys, IRT significantly extends the quality of information on the subsurface condition extracted from GPR only, and ACU can be used as an additional tool for mapping of the surface level defect locations.

Therefore, the proposed RPB HealTec concept provides the basis for further improvement of the existing pavement monitoring techniques, both, in time and accuracy, leading to optimization of pavement and bridge deck maintenance procedures.

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ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union's Seventh Framework Programme managed by REA-Research Executive Agency http://ec.europa.eu/research/rea ([FP7/2007-2013] [FP7/2007-2011]) under grant agreement No 606645- RPB HealTec.

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