Inspect-Roads: Towards road predictive maintenance

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***Abstract*—Inspect-Roads is a project focused on road maintenance thanks to computer vision and artificial intelligence techniques. Automatic road inspection improves road maintenance decisions. This project is a successful example of knowledge transfer from academia to industry.**

Keywords—road maintenance, computer vision, artificial intelligence.

I. Introduction

Maintaining a well-functioning road network is crucial for ensuring safe and efficient transportation. Roads are subject to wear and tear over time due to various factors such as weather conditions, heavy traffic, and aging infrastructure. This deterioration can lead to road defects, potholes, and ultimately, a decline in road quality.

To mitigate these issues and preserve the longevity of our roads, the concept of road predictive maintenance has emerged as a vital approach. Road predictive maintenance involves the use of advanced technologies and data-driven techniques to proactively identify, assess, and address potential road maintenance needs before they become severe problems. By leveraging predictive analytics, remote sensing, and condition monitoring, road authorities and transportation agencies can anticipate road deterioration patterns and plan targeted maintenance interventions.

The importance of road predictive maintenance cannot be overstated. It offers several significant benefits, including enhanced road safety, improved travel experience, cost savings, and increased infrastructure lifespan. By addressing maintenance needs proactively, road predictive maintenance reduces the likelihood of accidents and injuries caused by road defects, such as potholes and uneven surfaces. It also minimizes disruptions to traffic flow, as road repairs can be strategically scheduled and executed, avoiding unexpected closures and congestion.

Moreover, road predictive maintenance optimizes the allocation of resources and budgets. By identifying specific sections of roads that require attention, authorities can prioritize maintenance efforts and allocate resources more efficiently. This targeted approach reduces costs associated with reactive repairs and extends the lifespan of the road network. Additionally, by preventing further deterioration, road predictive maintenance helps avoid the need for extensive rehabilitation or reconstruction, which can be significantly more expensive and time-consuming.

Furthermore, road predictive maintenance contributes to sustainability and environmental conservation. Promptly addressing road defects and optimizing maintenance strategies minimizes the need for excessive construction materials, reduces energy consumption, and lowers carbon emissions associated with road repair activities.

Automatic methods based on computer vision and artificial intelligence are being used to solve this problem, however, the variety of the cases, the environmental conditions (such as fog, luminosity variations [1], etc.), and the subjectivity of the decisions, among others, require more effort.

In conclusion, road predictive maintenance plays a pivotal role in ensuring the longevity, safety, and efficiency of our road infrastructure.

II. Foundations of Road Crack Detection and Classification

Road crack detection and classification have emerged as critical components in road maintenance and management systems. Detecting and classifying cracks in pavement helps authorities identify areas in need of repair, prioritize maintenance efforts, and ensure the safety and longevity of road infrastructure. This section will explore the foundations of road crack detection and classification.

In [2], an efficient approach for pavement crack detection and classification was proposed. The work presented a novel algorithm that combined image processing techniques and machine learning algorithms to accurately detect and classify cracks in road pavement. The authors demonstrated the effectiveness of the method through extensive experiments on real-world datasets, achieving high accuracy rates in crack detection and classification.

The work presented in [3] explored the use of ensemble techniques to improve the accuracy and robustness of crack classification algorithms. Authors applied at first the following computer vision procedures: Feature extraction, color-space transformation, image enhancement, edge detection, morphological modifications, and, vertical and horizontal projections. Secondly, the machine methods: Decision trees (C4.5), LMT, and, RIPPER were compared with the Ensemble models proposed for 3 different datasets. The results highlighted the advantages of ensemble models in handling complex crack patterns and achieving higher classification performance compared to individual classifiers.

Recently, in [4], it was proposed a data dimensionality reduction method (DDR4CC) for improve road crack classification algorithms. This proposal uses as input a binarized image, and, reduces the number of parameters to 4: the maximum values of the accumulated row and column values, and, the difference between the maximum and the mean value for rows and columns.

Actual trends are focused on Deep Learning approaches, as can be seen in [5 – 7], however, most are focused just on cracks.

III. THE CHALLENGE

These works are focused just on cracks, some of them include potholes, however, other important defects are not being analyzed. A useful road predictive maintenance model requires also the inclusion of other types of defects, including deep potholes, shallow potholes, surface deterioration, edge failure, arc cracks, concrete jump, crazing, rutting, and subsidence.

Regarding computation, usually, a camera makes a shot of the road, and a post-processing step is carried out in supercomputers or powerful GPUs. Obtaining images of thousands of road kilometers with high resolution supposes a huge amount of data, most of it unnecessary, expensive systems, and high large energy consumption. Results obvious that an embedded onboard solution with real-time capabilities could be a better solution. However, this is not easy, because it involves high computation and complex algorithms, so, parallel optimization is required. The detection and classification of road defects are not enough for road predictive maintenance, also it is necessary to classify the importance of the defect.

IV. THE SOLUTION

Thanks to the Inspect-Roads project, CONACON, a Spanish company dedicated to road maintenance, and, the Advanced Informatics Research Group from the University of Córdoba collaborate to transfer scientific knowledge from academia to the industry and real society.

The first step of this project is obtaining a great dataset with real defects, to classify the type of defect, and also the degree of severity of each one.

The second step is training last-generation neural networks, although maybe it can be necessary for some previous image enhancement or other computer vision methods.

Following, the neural networks will be used to do real road inspections, and the results will be analyzed by civil engineering experts. As a result, we prevent detecting the necessity of improvements, obtain new images, and train again the neural networks.

The final step is obtaining a system capable of making accurate decisions and detecting and classifying the severity of detected road defects. The system also should get the GPS position of the defect, allowing its inclusion on a digital twin model.

The future after this project should advance in different aspects:

Optimization on embedded GPUs of the processing, avoiding registering millions of images, and just focusing on interesting information.

Enhanced Data Collection and Integration: Improving the collection and integration of data from various sources will be crucial. For instance, accelerometers provide essential information regarding some defects. Also, integrating data from IoT sensors, remote monitoring systems, and maintenance records, as well as incorporating external data such as weather patterns and traffic data.

Advanced Analytics and Machine Learning: Sophisticated algorithms can detect patterns, anomalies, and correlations to predict equipment failures or maintenance needs accurately. Applying techniques such as anomaly detection, deep learning, and reinforcement learning can help improve the accuracy and timeliness of predictions.

Real-time Monitoring and Decision-making: Integrating predictive maintenance systems with real-time monitoring and decision-making capabilities enables proactive decision-making and timely interventions, minimizing downtime and optimizing maintenance schedules.

Prescriptive Maintenance: While predictive maintenance utilizes historical data to predict future repairs, prescriptive maintenance goes a step further by considering both past performance data and the current condition of the road. By considering factors such as cost, resource availability, and operational constraints, prescriptive maintenance algorithms can suggest optimal maintenance actions, such as repair, replacement, or preventive measures. This approach maximizes asset performance and minimizes costs by balancing short-term and long-term maintenance needs.

Continuous Improvement and Learning: Predictive maintenance systems should continuously learn and adapt based on feedback and new data.

Digital Twins: By combining real-time data with digital twin models, predictive maintenance can simulate the impact of different maintenance scenarios, optimize maintenance strategies, and make data-driven decisions. Digital twins facilitate predictive maintenance by enabling a deeper understanding of asset performance and enabling condition-based maintenance.

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