Enhancing pavement performance evaluation via crowdsourced gamification

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ABSTRACT: This paper explores the innovative use of crowdsourced data for pavement evaluation through a gamification mobile application based on the ORAN platform. Leveraging proactive maintenance planning, this approach aims to substantially reduce costs associated with pavement management. The paper emphasizes the collection and evaluation of pavement data via crowdsourcing and artificial intelligence (AI) to address the critical lack of pavement distress data necessary for training AI models for distress detection and pavement condition prediction. Gamification is employed to motivate users to contribute valuable data, processed through edge computing for efficient pavement evaluation.

1 INTRODUCTION

Proactive maintenance planning is a method that foresees and corrects impending infrastructure issues before they become critical at minimal cost and with maximum pavement life. Traditional pavement survey methods are time-consuming and labor-intensive and hence are not very effective for the management of large road networks. A Pavement Management System (PMS) is a systematic method of formally assessing pavement conditions. It entails three significant phases: data collection, data analysis, and the development of maintenance and rehabilitation strategies. New technologies like mobile devices, artificial intelligence, and machine learning have significantly improved the accuracy and efficiency of pavement condition surveys. By integrating proactive maintenance strategies with these new technologies, PMS can simplify decision-making, enhance cost-effectiveness, and assist in ensuring the long-term performance and sustainability of road networks.

Proactive maintenance planning involves the timely identification of pavement conditions that require intervention before severe deterioration occurs. This approach is designed to minimize the lifecycle costs of pavements and extend their service life. By anticipating maintenance needs, agencies can allocate resources more efficiently, avoiding costly emergency repairs. The integration of proactive maintenance planning with modern technology provides a robust framework for sustainable infrastructure management.

Existing literature highlights the significant benefits of proactive maintenance planning in extending the lifespan of pavements and reducing overall maintenance costs (Shahin, 2005). Studies by Haas et al. (2010) emphasize the importance of timely interventions in preventing severe pavement deterioration. Furthermore, research by McNeil et al. (2014) demonstrates the effectiveness of crowdsourcing in collecting extensive and diversified data sets for infrastructure evaluation.

Crowdsourcing leverages the collective intelligence and efforts of a large group of individuals to perform tasks traditionally handled by designated professionals. In the context of pavement evaluation, crowdsourcing can facilitate the collection of extensive and diverse data sets from various locations, enhancing the comprehensiveness of pavement assessments.

Gamification has been widely studied in various domains for its potential to enhance user engagement and motivation (Hamari, Koivisto, & Sarsa, 2014). In the context of infrastructure management, Mora et al. (2016) explore the application of gamification to encourage public participation in data collection. Additionally, the integration of AI in infrastructure evaluation has shown promising results in improving the accuracy of distress detection and condition prediction (Voulodimos et al., 2018).

Artificial intelligence plays a crucial role in the automatic detection and classification of pavement distress. AI models require large datasets to accurately identify various types of distress and predict pavement conditions. However, the lack of extensive pavement distress data poses a challenge for training these models. Crowdsourced data offers a solution by providing diverse and abundant data to enhance the performance of AI algorithms. Edge computing,

a pivotal technology in this framework, has been proven to reduce latency and enhance real-time data processing capabilities (Shi et al., 2016). The combination of edge computing with AI and crowdsourced data collection presents a novel solution to address the existing gaps in pavement evaluation and maintenance planning.

2 RESEARCH OBJECTIVE

This paper proposes a novel solution by utilizing crowdsourced data through a gamified mobile application based on the ORAN platform. This method not only democratizes data collection but also harnesses the power of AI to provide accurate and timely pavement condition assessments.

3 RESEARCH METHODOLOGY

After development of a gamification-based mobile application , users capture images within designated areas displayed on the map. Defining these spatial boundaries helps manage data collection by prioritizing high-importance areas while preventing excessive focus on a single location. The system then analyzes the uploaded images or videos using advanced algorithms to process the content. Before anything else, the location tag of the content is checked to ensure it falls within the defined area. After that, the quality of uploaded content is evaluated based on the image processing algorithm. The system then detects and classifies various pavement distresses present in the images or video frames. Next, the user input is validated against AI predictions to ensure accuracy. Based on this validation, scores and rewards are assigned to users, motivating continued participation. The data collected through the ORAN platform is communicated to the cloud,enabling the creation of a color-coded map that demonstrates pavement conditions at the network level and can also be used to develop a digital twin model to accurately represent how the road deteriorates and degrades over time.

To motivate users to participate in data collection, the mobile application incorporates gamification elements. Users are divided into two categories: experts and non-experts. Experts are responsible for capturing and labeling pavement distress images with specific types and severity levels. Although this data is highly valuable, it requires expertise and effort. Non-experts, on the other hand, can contribute by taking pictures or videos of pavement distress under two options: simply indicating the presence of distress or categorizing it into one of five general groups. Naturally, labeling specific distress types carries a higher score compared to selecting a general category, as it provides more valuable data. Players receive scores and rewards based on the accuracy and relevance of their contributions, with experts earning higher points. Additionally, non-expert players are encouraged to attempt specific distress labeling, as it offers a path toward becoming expert users, further enhancing engagement and data quality.

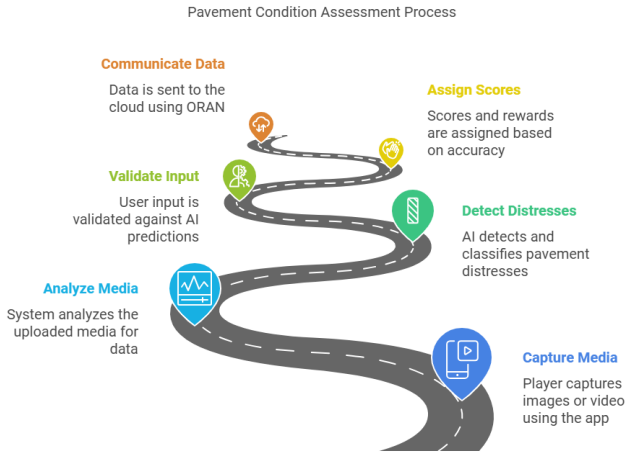

Figure 1. Pavement condition assessment process.

The mobile application allows users to capture images or videos of pavement conditions while walking or driving. These contributions are analyzed using edge computing, which employs lightweight and fast deep learning algorithms such as YOLO (You Only Look Once). The edge cloud processes the data, providing immediate feedback and rewards to users, thereby maintaining their engagement and ensuring the continuous flow of data via ORAN to the cloud for pavement condition demonstration at the network level. The workflow of the pavement condition assessment process is illustrated in Figure 1, detailing the sequential steps from media capture to score assignment.

4 CROWDSOURCING AND GAMIFICATION FOR PAVEMENT DATA COLLECTION

The proposed mobile application utilizes crowdsourcing to gather pavement condition data from two types of users: experts and non-experts. By incorporating gamification elements, the app motivates users to actively participate in data collection, making the process more engaging and enjoyable. To effectively encourage participation, it is essential to stimulate both intrinsic and extrinsic motivation. Extrinsic motivation can be reinforced through financial incentives or even free urban services, providing tangible rewards for contributions. However, intrinsic motivation, which plays a far more significant role in sustaining engagement, is primarily driven by gamification elements. By making the experience interactive, rewarding, and goal-oriented, the app fosters a sense of achievement, self-worth,

and enjoyment, encouraging users to contribute consistently.

Expert users, such as civil engineers or trained inspectors, can contribute high-quality data by capturing images of pavement distresses and labeling the distress type and severity. This data is particularly valuable for training AI models but may be less motivating for users due to its technical nature. To encourage participation, the app implements a points system and leaderboards, recognizing top contributors and fostering healthy competition among experts. Non-expert users, such as the general public or citizen scientists, can contribute in two ways: basic distress reporting, where users simply indicate the presence of a distress on the pavement, and general categorization, where users select from five predefined distress groups. Additionally, users can choose their data collection method, such as walking mode, capturing individual images, driving or riding mode, recording video footage. The interplay between user expertise and data quality in pavement distress reporting is presented in Figure 2, providing insights into the categorization and reporting accuracy.

Figure 2. Interplay matrix between user expertise and data quality in pavement distress reporting and categorization.

5 OPEN RADIO ACCESS NETWORK

Using Open Radio Access Network (ORAN) for data storage and sharing offers an innovative approach to managing crowdsourced pavement image data collected through a gamified mobile application. The platform engages users to capture and upload pavement images, incentivizing participation through gamification elements such as points, rewards, and leaderboards. ORAN's decentralized and interoperable infrastructure ensures efficient handling of this data by enabling scalable, low-latency storage and real-time sharing across multiple stakeholders. This setup facilitates seamless collaboration between researchers, road authorities, and developers while maintaining data integrity and privacy. Moreover, the data ultimately belongs to the company investing in this idea, and in keeping with the democratic spirit of the project, the results can be shared with councils and urban authorities for public viewing—thereby stimulating citizen advocacy and accelerating improvements in repair and maintenance processes. By leveraging ORAN's capabilities, the system enhances data accessibility and accelerates the analysis of pavement conditions, ultimately supporting more efficient maintenance planning and decision-making.

To provide real-time feedback and maintain user engagement, the application leverages edge computing capabilities through the ORAN platform. This allows for quick processing of captured images and videos using lightweight deep learning algorithms such as YOLO (You Only Look Once). The edge computing system performs tasks such as analyzing uploaded images or video frames, detecting and classifying pavement distresses, validating user input against AI predictions, and assigning scores and rewards to users based on accuracy. This immediate feedback loop not only gamifies the experience but also helps improve the quality of crowdsourced data over time. Figure 3 outlines the research methodology employed in this study, offering a structured overview of the processes and techniques utilized.
Moreover, regions that lack access to advanced and expensive technologies, such as Connected and Automated Vehicles (CAVs), can still benefit from this approach, as it only requires smartphones, which are widely available. Users can also participate through different modes—walking mode for capturing individual images or driving/riding mode for recording videos—providing flexibility in data collection across various road environments.

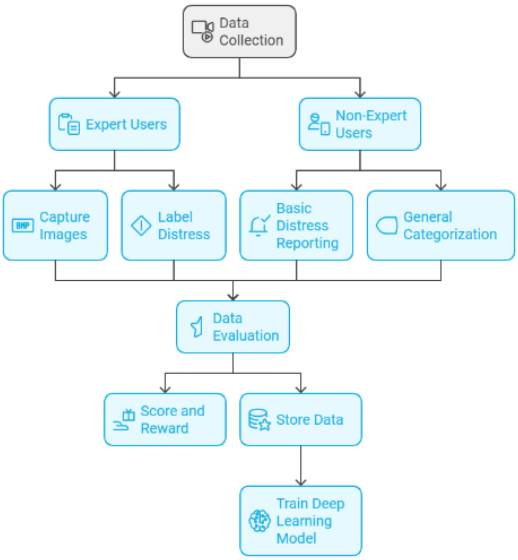

Figure 3. Research methodology.

6 INITIAL RESULTS

Initial results indicate that players have engaged with the gamified mobile application exceptionally well, capturing a substantial number of images. The app's ability to recognize, evaluate, and score these

images accurately has proven effective, providing immediate feedback and incentives that maintain player motivation. This high level of engagement and the quality of data collected demonstrate the app's potential as a significant source of information for proactive maintenance planning. Figure 4 showcases screenshots of the gamification-based mobile application developed on the ORAN platform, highlighting its user interface and functionalities.

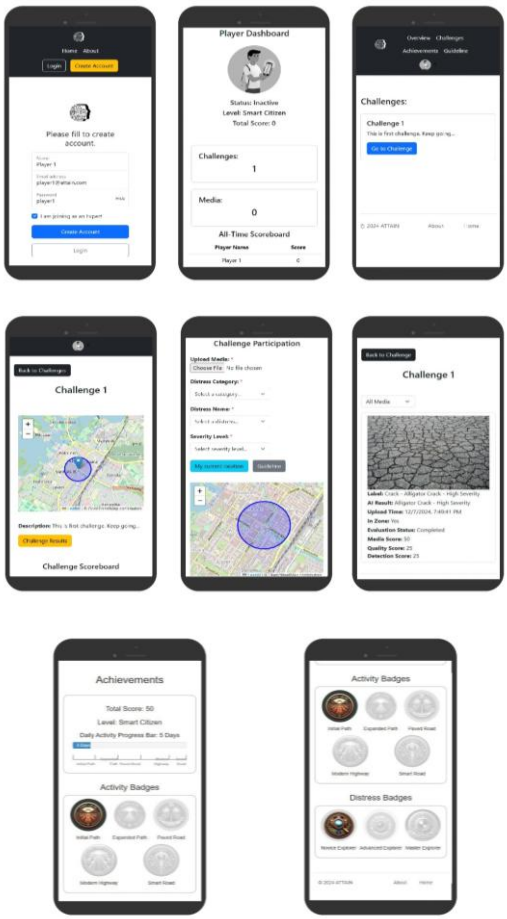

Figure 4. Screenshots of gamification mobile application based on the ORAN platform.

7 LIMITATIONS AND FUTURE WORK

While the proposed system offers numerous benefits, including increased data volume, diverse data sources, cost-effective data collection, real-time pavement monitoring, enhanced public engagement, and improved AI model performance, it also faces several challenges. Ensuring data quality control and minimizing false reports from non-expert contributions are critical concerns. Additionally, robust measures must be implemented to protect user privacy and data security. Sustained user engagement over time is essential, requiring long-term strategies to keep users interested and participating. Integrating the crowdsourced data seamlessly with existing pavement management systems presents another significant challenge. Future work will focus on refining the gamification elements, enhancing AI algorithms for more accurate distress detection, and developing methods to integrate crowdsourced data with traditional pavement management practices, thus ensuring the system's overall effectiveness and efficiency. Furthermore, future research could explore leveraging and combining additional mobile phone sensors to enhance data accuracy and reliability. It is also important to acknowledge the limitation in determining the precise location of the photographed area when the mobile device was not physically present at that location.

8 CONCLUSION

The use of crowdsourced data for pavement evaluation through a gamification mobile application based on the ORAN platform presents a transformative approach to infrastructure management. By leveraging proactive maintenance planning, crowdsourcing, AI, and edge computing, this method addresses the critical data gap and enhances the accuracy and efficiency of pavement condition assessments. The engagement of both experts and non-experts in data collection ensures a comprehensive and continuous flow of valuable data, ultimately contributing to sustainable and cost-effective pavement management. While the adoption of emerging data collection technologies such as connected and automated vehicles (CAVs) from OEMs is recognized as highly valuable, the complementary advantages of the crowdsourcing approach help address various challenges in pavement management.

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