System for Quality of Traffic Infrastructure Measurements

Miloslav Slodičák, Michal Hodoň, Juraj Miček, Peter Ševčík

***Abstract*—**This paper presents the development of a system designed to evaluate the quality of traffic infrastructure by integrating a custom-built sensor prototype with an Android application. The system leverages sensor data to detect road surface irregularities, providing users and authorities with actionable insights. The sensor module records acceleration and vibration data, which are processed to identify critical road conditions. A mobile application visualizes this data in real time, enhancing user interaction and data accessibility. This work outlines the hardware and software design, experimental validation, and potential applications in traffic monitoring and urban planning.

***Keywords*—**Traffic infrastructure, road quality monitoring, sensor prototype, Android application, IoT.

I. Introduction

The quality of traffic infrastructure directly influences safety, vehicle maintenance costs, and the overall efficiency of transportation networks. Poor road conditions, including potholes, uneven surfaces, and structural degradation, can lead to accidents, increased fuel consumption, and higher maintenance expenses for vehicles. As urbanization accelerates, maintaining road infrastructure has become a critical priority for municipalities and governments worldwide. Effective monitoring systems are essential for identifying problematic areas, prioritizing repairs, and optimizing resource allocation [1][2]. Traditional methods of assessing road quality rely heavily on manual inspections or specialized vehicles equipped with expensive instrumentation, such as high-resolution cameras, laser scanners, and accelerometers. These approaches, while accurate, are labor-intensive, costly, and limited in scalability. Manual inspections are subject to human error and cannot provide real-time or large-scale data. On the other hand, specialized vehicles, though effective, are often constrained by their high operational costs and dependency on trained personnel [3]. Consequently, there is a growing demand for more accessible and scalable solutions that leverage modern technologies to monitor traffic infrastructure efficiently. The emergence of Internet of Things (IoT) technologies has introduced a transformative approach to infrastructure monitoring. IoT devices, characterized by their low cost, portability, and connectivity, offer significant advantages in scalability and real-time data acquisition. Recent advancements in microcontrollers, sensors, and mobile applications have enabled the development of systems that can collect, process, and visualize data on road quality using everyday vehicles as data collectors. For example, systems like Pothole Patrol and SmartRoads have demonstrated the feasibility of using accelerometers and GPS-equipped smartphones for detecting road anomalies. However, these solutions face challenges in data accuracy due to noise from vehicle-specific factors and environmental conditions [4][5]. This study introduces a cost-effective system for monitoring traffic infrastructure quality using a custom-built sensor prototype and an Android application. The sensor module combines an MPU-6050 accelerometer and gyroscope with an ESP32 microcontroller for data acquisition and processing. The Android application provides real-time visualization, geolocation integration, and user interaction

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features. The system leverages Bluetooth Low Energy (BLE) communication for efficient data transmission and integrates GPS data to map road conditions across different locations. Unlike existing systems, the proposed solution emphasizes ease of deployment, portability, and user accessibility, making it suitable for both individual users and municipal authorities.

In addition to addressing the limitations of traditional methods, the proposed system incorporates state-of-the-art advancements in IoT and sensor technology to enhance data accuracy and reliability. The MPU-6050, a widely used motion tracking sensor, offers precise acceleration and angular velocity measurements, enabling the detection of subtle road irregularities. The ESP32 microcontroller facilitates real-time processing and seamless communication with the mobile application. Furthermore, the system's modular architecture allows for scalability and integration with advanced data analytics tools, such as machine learning algorithms, to predict infrastructure deterioration trends [6][7]. This paper outlines the design, implementation, and validation of the system, highlighting its potential applications in traffic management, urban planning, and predictive maintenance. By combining real-time data acquisition with intuitive visualization, the system aims to democratize access to road quality information, enabling users to actively participate in infrastructure monitoring and decision-making.

II. INTEGRATION

The methodology for developing the traffic infrastructure quality monitoring system focused on integrating hardware and software components into a functional, scalable, and user-friendly solution for road condition assessment. The system's core hardware comprises an MPU-6050 accelerometer and gyroscope module, an ESP32 microcontroller, and a rechargeable battery, all housed within a compact and portable casing. The MPU-6050 module was selected for its ability to provide precise acceleration and angular velocity measurements, essential for detecting vibrations and motion patterns indicative of road irregularities. The ESP32 microcontroller, chosen for its processing power and Bluetooth Low Energy (BLE) capabilities, handles data acquisition, processing, and communication with the Android application. The rechargeable Li-Pol battery powers the system, ensuring portability and extended operational duration. The hardware design emphasized modularity, allowing for easy replacement or upgrading of individual components without affecting the overall functionality of the system.

The software for the sensor prototype was developed using the Arduino IDE, with a focus on real-time data acquisition and processing. The ESP32 microcontroller collects raw data from the MPU-6050 sensor at predefined intervals, filters out noise using a low-pass filter, and calculates key metrics such as vibration intensity and orientation deviations. These metrics are processed to identify road conditions that fall into predefined categories such as smooth, moderate, or poor. The processed data is then packaged and transmitted to the Android application via BLE. To ensure reliability and reduce latency, the BLE communication protocol was optimized to minimize packet loss and maximize transmission speed. The Android application, developed using Kotlin in Android Studio, interfaces with the sensor prototype to visualize real-time data and provide geolocation-based mapping of road conditions. The application integrates GPS functionality to associate sensor readings with specific locations, creating a spatially resolved map of road quality. Additional features include user logging capabilities, allowing individuals to manually tag specific road events such as potholes or construction zones, enhancing the system's data granularity.

System integration was achieved by establishing a seamless communication pipeline between the sensor prototype and the Android application. The microcontroller continuously streams data to the mobile device, where it is displayed using graphical tools, including line graphs and heat maps, to offer intuitive insights into road conditions. The modular architecture of the system enables scalability, allowing multiple sensor prototypes to operate concurrently and send data to the same application for broader area coverage. Testing and calibration were integral to the development process, with extensive evaluations conducted in controlled and real-world environments. Calibration ensured that the MPU-6050 sensor accurately measured acceleration and angular velocity, while thresholds for vibration intensity were fine-tuned to distinguish between normal vehicle motion and road surface irregularities. Real-world tests involved driving over various road types to assess the system's performance in detecting and categorizing road quality accurately. Power efficiency was another critical aspect addressed during the development process. The ESP32 microcontroller's sleep modes were utilized to reduce power consumption during periods of inactivity, extending the operational life of the battery. Additionally, the Android application was optimized to minimize resource usage while maintaining responsiveness and functionality. Challenges encountered during development included handling environmental noise and external vibrations unrelated to road conditions, which were mitigated using software-based filtering techniques. The methodology ensured a robust, portable, and cost-effective solution that combines accurate road quality assessment with intuitive visualization, making it suitable for diverse applications in traffic monitoring, urban planning, and infrastructure maintenance. Future iterations of the system could integrate machine learning algorithms to further enhance data classification and provide predictive analytics for proactive infrastructure management.

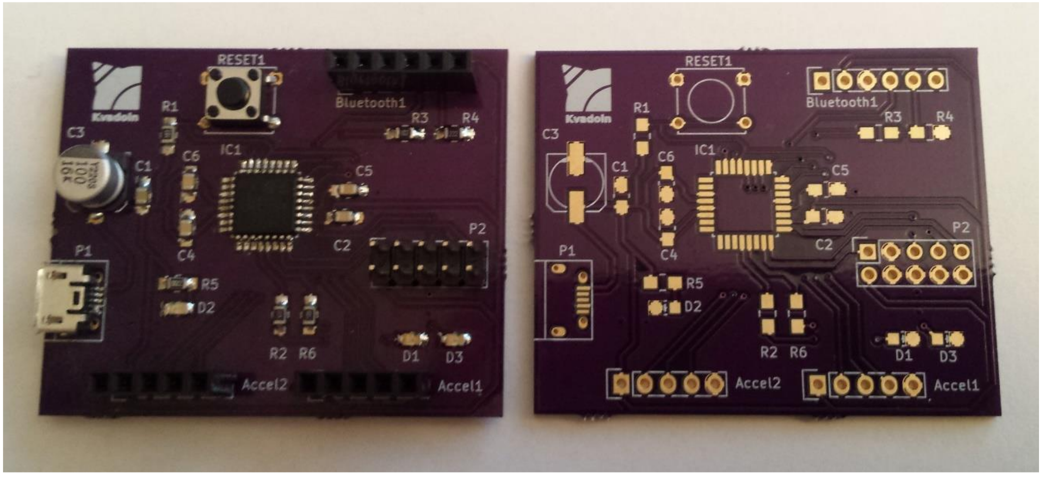

Fig. 1 Developed device

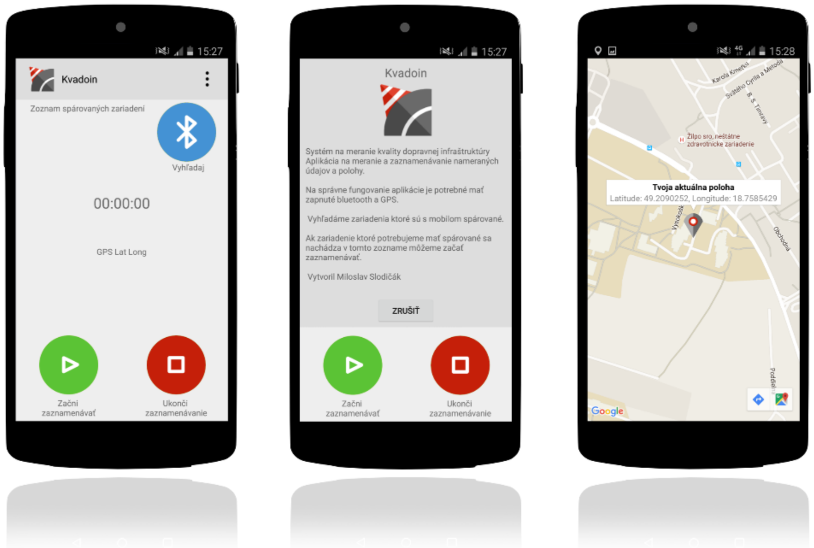

Fig. 2 Graphical interface

Fig. 3 Measurement scenario

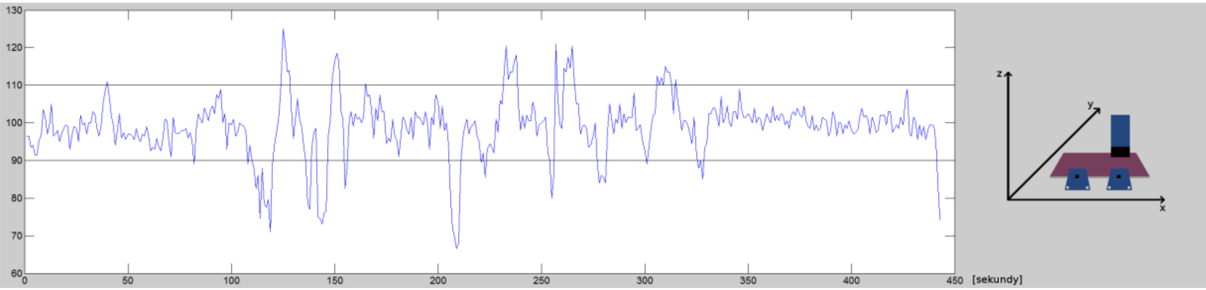

Fig. 4 Measured results on the 1st class highway route 66

III. Conclusion

The system was tested in various real-world conditions, including urban streets and highways. The sensor module successfully detected road surface irregularities with a high degree of accuracy, correlating with manually observed conditions. Bluetooth communication between the sensor and the application remained stable across different environments, with minimal data loss. The Android application provided clear and actionable insights, with users reporting high satisfaction in terms of ease of use and responsiveness. Experimental results demonstrated the system's ability to classify road conditions into categories, such as smooth, moderate, and poor, based on vibration intensity metrics. The proposed system offers a cost-effective and scalable solution for road quality monitoring, addressing limitations of traditional methods. By leveraging widely available hardware components and an intuitive mobile application, the system democratizes access to road condition data. However, certain challenges remain, including sensor sensitivity to external vibrations unrelated to road quality (e.g., vehicle-specific factors) and potential connectivity issues in dense urban areas. Future iterations could incorporate machine learning algorithms to enhance data classification and expand functionality to include additional metrics, such as noise pollution. This study successfully developed and validated a system for monitoring traffic infrastructure quality. The integration of a custom sensor module and an Android application provides a portable, accessible, and scalable solution for identifying and addressing road surface irregularities. The system has significant potential applications in urban planning, road maintenance, and traffic management, offering insights that can improve safety and efficiency on roads. Future research could explore enhancing system robustness and integrating advanced analytics for predictive maintenance.

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