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CHALLENGES IN REAL-TIME LOW-COST VEHICLE RECOGNITION SYSTEMS FOR CNOSSOS-EU INPUT

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ABSTRACT

The present paper describes the main issue to take into account to reach the implementation of an advanced system for real-time vehicle classification. Real-time vehicle identification is critical for traffic monitoring to mitigate traffic congestions, noise and air pollution, and in this context CNOSSOS-EU method included in the Annex II of the directive 2002/49/EC classes provides a common framework for acoustic classification of vehicles. Previous systems using road cameras and artificial intelligence models demonstrated promising results; however, they failed to meet real-time requirements mainly due to computational complexity and a lack of robustness in handling challenging environmental conditions. The present work evaluates the actual limitations and challenges arose in the development of an improved system able leverages edge computation, processing directly at the point of acquisition, for vehicle classification in applications such as environmental monitoring and dynamic traffic management.

Keywords: *real-time vehicle detection, low-cost sensors, CNOSSOS-EU model, road traffic noise, noise management*

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1. INTRODUCTION

Live road monitoring has become a pivotal component of environmental studies, as it facilitates the acquisition of precise traffic flow data. This data is of paramount importance when employing standardized methodologies, such as the Common Noise Assessment Methods (CNOSSOS-EU), mandatory for the realisation of road noise mapping in the European Union [1–5] .

In urban areas, the primary source of acoustic pollution is the noise generated by road infrastructure; therefore, precise and effective mapping is crucial [6]. This highlights the need for reliable and accurate traffic data [7–9]. Several innovative methods for intelligent acquisition of traffic data based on video [10–12] have emerged recently, but they are all designed for different applications and may not be optimal for acoustic modelling. They are also often too expensive for large-scale implementation.

The combination of Intelligent Transportation Systems, traffic monitoring and noise pollution reduction in urban areas was previously investigated by the authors in a pioneer study [13] where low-cost cameras aided by machine learning techniques were employed for vehicle recognition and counting. However, the first trial had yielded promising results but had several limitations in terms of real applicability and scalability.

The present work examines the main challenges in properly improving efficiency and durability of a real-time and low-cost vehicle recognition system. Starting from the improvements towards real-time evolution shown in [14], the traffic monitoring systems is examined from both the hardware and software points of view. Limitations and solutions towards low-cost and durable real-time systems are investigated. The primary constraints imposed by the objective of cost minimisation are highlighted, particularly those related to computational efficiency, model accuracy and scalability of machine learning approaches, as well as hardware constraints such as camera resolution, processing power and system integration. A particular focus is directed towards security from the perspective of liability, the privacy of collected data, and the prevention of damage and theft, aspects that are frequently underestimated in existing systems. By identifying these critical issues, the objective is to propose improvements that enhance the feasibility and reliability of real-time traffic monitoring solutions while maintaining the system at a minimal cost. The importance of a low-cost system in the domain of traffic monitoring is underscored by its capacity to facilitate the installation of a greater number of detection devices, thereby enhancing the accuracy of model generation through the aggregation of a more substantial dataset.

2. MATERIAL

The work of Profumo et al. [14] is a significant example of a real-time system that aims to identify and classify road vehicles according to the specifications of the CNOSSOS-EU model.

This sections provides a concise overview of the improvable aspects of the proposed monitoring system in terms of durability and performance. This offers a general indication of the strategies to be adopted to achieve an effective and long-term real-time architecture.

The system was developed using low-cost hardware and advanced computational techniques, and was able to operate in real-time without requiring post-processing of the videos, with higher efficiency and accuracy than existing commercial solutions.

The hardware components comprise a Raspberry Pi 4 equipped with a Coral TPU accelerator, a low-resolution camera with a protective case (Fig. 1) and a portable battery. The software component is based on deep learning algorithms, in particular object detection models such as YOLOv8, which are optimised through quantisation processes to reduce energy consumption and improve inference speed. To monitor the movement of vehicles between video frames, the system also integrates advanced tracking algorithms such as SORT, DeepSORT, ByteTrack and BOTSort, improving the analysis capability in complex scenarios.

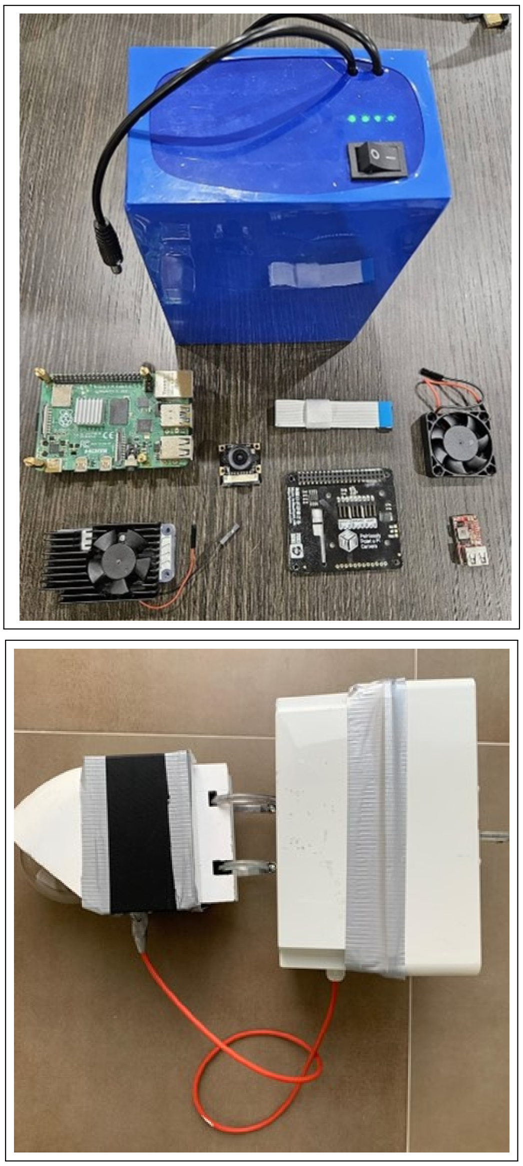

Figure 1. Hardware setting used in [14].

3. HARDWARE SET-UP CHALLENGES

The purpose of implementing a real-time traffic monitoring system is to ensure its effective and durable performance under all conditions, thereby facilitating accurate mapping of traffic patterns. The primary hardware issues identified in the system under analysis, which are also applicable to many low-cost systems currently under development, can be categorised into two overarching categories based on their impact on system characteristics: durability and high performance. In addition, the security implications of a robust and compliant hardware componentry are analysed in more detail in the following sections.

3.1 Durability

Durability represents a significant challenge for traffic monitoring systems currently available on the market. This durability is defined by the system's resistance to atmospheric conditions, temperature fluctuations, and the system's ability to withstand the passage of time without suffering damage, thereby ensuring comparable performance to that obtained after installation. The utilisation of low-cost processing boards, frequently equipped with external accelerators, as exemplified by Profumo et al. [14], can result in the accumulation of heat within the containment boxes. This phenomenon can precipitate dissipation issues, potentially leading to the system's failure after a brief period of utilisation. Furthermore, even in the event of the implementation of external dissipation strategies, such as the use of fans or insulating materials, the combination of these measures with high external temperatures frequently results in overheating, which often leads to malfunctions or even irreversible damage to components.

Conversely, the usage of low-cost calculation systems restricts the selection of video capture devices themselves, resulting in the recourse to low-resolution cameras that frequently prove inadequate in withstanding the rigours of unfavourable weather conditions. Indeed, high computing performance is often only assured for a limited number of frames to be analysed, as well as by the substandard quality of the images themselves. The selection of this type of camera, although effective in achieving the desired outcome, is accompanied by significant drawbacks. The most salient drawback is the necessity to equip the camera with protective housings, which can introduce additional distortion factors into the image, thereby complicating its analysis. Moreover, such cases frequently necessitate bespoke designs, which are not supplied or patented by the manufacturers of the devices, as they are not intended for outdoor or inclement weather conditions. This factor, in turn, gives rise to problems relating to the durability of the case itself, which, being not perfectly compliant with the use to which it is put, may incur damage or situations that affect video capture. In fact, Profumo et al. [14]have encountered phenomena of moisture accumulation and condensation due to both temperature changes and the presence of rain, conditions that have made it impossible to process videos captured in such contexts.

In the context of low-cost systems, a salient issue pertains to the durability of power supply mechanisms. Rather than employing direct power supply systems, these systems frequently use batteries, and in the most favourable scenario, solar panels to achieve autonomy. However, these solutions necessitate regular maintenance due to the replacement of non-rechargeable batteries and the deterioration of solar panel systems over time.

Finally, the deployment of hardware that is not designed for outdoor use, and frequently incorporates components not intended for that specific application, poses significant safety risks. Firstly, the installation process, which in traffic monitoring contexts is clearly executed in an urban environment, necessitates specialised care to ensure that it does not pose a threat to citizens or vehicles. This cannot be assured with this type of equipment. Furthermore, it is imperative to ensure that the system is resilient to acts of vandalism, tampering or theft, both from economic perspectives and to avert a potential breach of privacy concerning the data collected.

3.2 Performance

In terms of performance, which is understood to mean the capacity to facilitate complex calculations (e.g. recognition models, tracking, data analysis) in real-time whilst ensuring the accuracy of results and minimising energy consumption, the extant systems have these characteristics. However, they generally achieve this at the expense of other variables that are equally important, if not more, such as computational capacity and the possibility of using more powerful video acquisition devices. The result is that it is not possible to monitor in all light or weather conditions.

The issue with the prevalent low-cost systems currently available is that they possess constrained computational resources. Devices such as the Raspberry Pi, though equipped with a Coral TPU accelerator (see [14]), exhibit significant limitations in their capacity to process complex models. While quantized models demonstrate energy and computational resource savings, this approach compromises detection accuracy in comparison to full models executed on more powerful GPUs.

However, the architecture of these types of systems is designed to be compact and low energy, so that they are easy to install and have little visual impact on urban road infrastructure, but this poses significant constraints on scalability. This prevents the integration of advanced technologies, such as radar or lidar sensors, which would improve classification accuracy.

As previously introduced, the choice of low-resolution cameras has a significant impact on system performance in low-light, night-time or low-visibility environments. This severely limits the reliability of data in traffic modelling at night or in low light. The same order of problems impacts adverse weather conditions, such as dust, rain, or sun glare, which can affect video footage, creating visual noise that complicates object detection.

As previously mentioned, the selection of low-resolution cameras has a substantial impact on the performance of the system in low-light, night-time, or low-visibility environments. This significantly restricts the reliability of data in traffic modelling during nocturnal hours or in conditions of reduced illumination. A similar set of problems is encountered in adverse weather conditions, such as dust, rain, or sun glare, which can affect video footage, resulting in visual noise that complicates object detection.

4. SOFTWARE CHALLENGES

In addition to hardware limitations, there are also software limitations that hinder full real-time operation, the improvement of which is strictly dependent on the enhancement of acquisition and processing components. The introduction of cameras with higher resolution, and perhaps infrared, often weatherproof cameras, results in greater freedom in the development of models capable of vehicle recognition from different angles and in all weather conditions. This, in turn, makes the system more efficient by improving data quality and ensuring truly real-time processing without constraints.

Furthermore, the implementation of more advanced processing boards, while not accompanied by a significant escalation in cost, would facilitate the selection of models that are characterised by more intricate infrastructures. This would ensure the maintenance of efficient performance, thereby mitigating the loss of precision that is often associated with the quantization processes necessary to ensure the efficacy of neural networks on computing devices with lower performance capabilities.

In terms of security, the employment of devices that are approved for outdoor use, such as cameras intended for video surveillance, is frequently accompanied by the integration of data protection software. This aspect would be rendered significantly more straightforward.

5. DISCUSSION AND CONCLUSIONS

This work provided a general analysis of the main limitations in developing an effective, durable, and efficient real-time traffic monitoring system based on video acquisition. The primary challenges—both hardware- and software-related are discussed, highlighting the components that most significantly affect the achievement of this goal.

From a hardware perspective, the focus was on two fundamental principles: durability and performance. The most common issues associated with low-cost systems currently used for similar purposes are outlined. On the software side, it was shown how improvements in hardware can lead to notable advancements in the AI models used for vehicle tracking and classification.

The team is currently working on the development of a vehicle recognition system designed to address the issues discussed in the article. The system includes a weather-resistant camera capable of ensuring visibility even at night or in low-light conditions, thanks to the integration of infrared technology.

For processing, a board equipped with an integrated GPU is used to maximize performance and enable fast classification times. Finally, to fully meet the requirements of a real-time system, rapid access to the processed data is essential. For this reason, the system features an internet connection that allows the data to be transmitted to a server with a dedicated database.

An equally important aspect is the acoustic application of real-time traffic data. The availability of up-to-date and precise traffic flow information is essential for the accurate application of standardized noise mapping methodologies such as CNOSSOS-EU. Real-time data not only improves the temporal resolution of noise models, but also allows for dynamic noise mapping, which can be used to assess fluctuations in urban acoustic noise throughout the day. This capability is particularly relevant for environmental monitoring, urban planning, and the implementation of adaptive mitigation strategies aimed at reducing noise exposure in sensitive areas.

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