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EVALUATION INDEX FOR SPORTY ENGINE SOUND REFLECTING EVALUATORS' TASTES, DEVELOPED USING K-MEANS CLUSTER ANALYSIS

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ABSTRACT–Developments in vehicle technology and accompanying improvements in NVH performance have led to increased consumer demand for high sound quality, such as a "sporty" engine sound. As sporty sound is subjective, this study sought to express its meaning quantitatively and to develop a model that accommodates the differences in individuals' tastes. Engine sounds of four vehicles at wide-open throttle were recorded and the signal was modulated via filtering. Acoustic and psychoacoustic parameters of the samples produced were calculated, and the preferences for sportiness were identified through jury testing. Using K-means clustering, factor analysis, and multiple linear regression, a sound quality index and a model reflecting differences in evaluators' tastes were developed. The index was retested using new evaluators and new samples, demonstrating its reliability by high correlation. This sound quality evaluation index is useful for producing highly accurate results and reflecting the opinions of groups expressing a variety of commonalities.

KEY WORDS : K-means clustering, Multiple linear regression, Psychoacoustic, Sound quality index, Sportiness, Vehicle engine sound

NOMENCLATURE

$\hat{\boldsymbol{k}}^{(n)}$: initial estimated value identifying the cluster
$\boldsymbol{m}^{(k)}$: centroid
$\boldsymbol{x}^{(n)}$: data point
$\boldsymbol{R}^{(k)}$: number of data in the cluster
y_i : dependent variable
β_0 : constant
β_p : regression coefficient
e_i : error
$\mathbf{SPL_{OA}}$: A-weighted sound pressure level

1. INTRODUCTION

This study sought to determine how to identify a "sporty engine sound" in terms of sounds from an engine, which is the main source of sound generated by a vehicle. Moreover, the study sought to determine how to objectify the subjective concept of "sportiness" and increase its accuracy. To achieve these objectives, we focused on classifying the tastes of evaluators by analyzing preferences with regard to the engine sounds people would feel are "sporty" and by applying the K-means clustering algorithm. The study additionally applied a multiple linear regression analysis based on the classified values to derive regression equations, thereby quantifying the results.

Recently, the influence of AI, arising from the Fourth Industrial Revolution (Byeon, 2017), has also been felt in the field of noise, vibration, and harshness (NVH). Electric vehicles and the like may also reduce interest in internal combustion engines, which are still the main power sources for most vehicles. However, because of various factors including marketability, supply infrastructure, and price issues, there is still a need for competitive and ongoing research (Lee, 2018). Furthermore, in the last few decades, there has been a rise in consumer demand for good sound rather than for simple noise reduction in internal combustion engines. Consequently, researchers must continuously investigate the quality of various sounds generated by vehicles in addition to those of the engine. Many relevant results are presented here. Kwon *et al.* (2018) identified the sound quality metrics that have an effect when loudness is excluded, which normally dominates vehicle interior sound to provide a sporty image. He *et al.* (2019) proposed a structure–loudness model to represent exhaust tail noise according to structural differences in the exhaust system. Lee *et al.* (2019) proposed a method to predict changes in the sound inside a car cabin with respect to variations in absorption materials. In addition, researchers have investigated methods for improving and objectifying various types of vehicle-generated noise, including window movement sounds (Jo

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