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Review

The doctoral dissertation of Muhammad Ahsan, MSc, entitled:

"Vehicle Diagnostics using Artificial Intelligence and Digital Signal Processing Methods".

Formal basis for the preparation of the review:

The review of the dissertation by Muhammad Ahsan, MSc, was prepared in accordance with the resolution of the Discipline Council for Automation, Electronics, Electrical Engineering and Space Technologies of the Silesian University of Technology dated 18 March 2025.

1. Notes on the choice of subject matter for the dissertation

Thanks to the development of the automotive industry, cars are objects of common use. Safe, comfortable, trouble-free operation of these complex machines is conditioned by monitoring changes in the parameters of physical or chemical processes accompanying the operation of individual mechanisms and assemblies.

Control systems are being continuously improved, modern cars are equipped with solutions limiting the need for human involvement in the interpretation of operating parameters; the base of features - sources of information on potential damage or failures - is being expanded. Vibroacoustic processes, especially vibrations recorded at selected points on the machine, are becoming increasingly important for diagnostics.

Given the above, I believe that the topic of the dissertation is valid, and that research into the use of digital processing of vibration signals and artificial intelligence for vehicle diagnosis is of utilitarian and scientific importance.

2. Characteristics of the dissertation

The dissertation submitted for evaluation consists of 179 pages. The main substantive part contains 119 pages of text including figures and tables. The remainder consists of: 2 title pages, Author's declaration, acknowledgements, table of contents, list of figures, list of tables, abstracts in English and Polish, list of Author's publications, bibliography of 126 items and 6 appendices (technical data of vibration recorder elements, description of calculation procedures, verification results for the effectiveness of machine learning in relation to the model structures).

In the first chapter entitled "Introduction", the Author signals the advisability of diagnostics of automotive internal combustion engines using vibration signals processed with miniature MEMS accelerometers, draws attention to the possibility of analysis in the time and frequency domains, emphasises the role of machine learning and artificial intelligence methods in the diagnostic aspects, and presents the scope and structure of the dissertation.

The second chapter contains basic information about the accelerometer and microcontroller on the basis of which the vibration acquisition and processing set-up was built, and about the calibration of the measurement path.

In the third chapter, the PhD candidate discussed a bench experiment, during which the time courses of vibration acceleration of a passenger car engine were recorded at several speeds with different loads under conditions of a given ignition system fault. The author also presented the literature sources of the datasets used for the dissertation with recorded rolling bearing vibrations, together with a description of these studies. I consider experimental research using the author's vibration recorder to be an important part of the dissertation.

Chapter four is devoted to the issues of digital signal processing in the aspect of diagnosing selected vehicle faults. Among other things, attention was paid to the advantages and limitations of the fast Fourier transform, the design of filters optimised for specific faults, the usefulness of envelope analysis and the wavelet transform for fault detection.

In the next chapter, the PhD candidate discussed the usefulness of artificial intelligence methods for diagnosing internal combustion engine ignition faults. In particular, he analysed the efficiency of inference using neural networks operating on one- and two-dimensional representations of vibration patterns.

The author presented a summary of the obtained research results in the last, sixth chapter. He highlighted the potential of artificial intelligence-supported low-budget hardware platforms based on MEMS accelerometers in machine diagnostics, while signalling the limitations of such solutions. The PhD candidate also indicated the desirability of extending the variety of data and continuing efforts leading to the possibility of automating diagnostic inference in real time. The achieved results encourage further improvement of the methodology with high application potential.

3. Evaluation of the dissertation

The dissertation is multidisciplinary by nature, covering issues falling within the field of engineering and technical sciences. The qualification of the dissertation to the discipline of automation, electronics, electrotechnology and space technologies results from the application by the PhD candidate of methods and means of information processing typical for the area of this discipline.

The presented literature review reflects the current state of knowledge, refers to previous research related to the subject matter of the work conducted in foreign and domestic centres. I consider the choice of literature presented by the author to be apt and the manner of citation correct. It testifies to the author's ability to use bibliographic material. The author's own publication output related to the dissertation issues should be emphasised, which includes 4 co-authored articles in recognised scientific journals and 4 conference publications.

As the aim of the dissertation, the author indicated solving the problems of vehicle fault diagnosis by integrating modern transducers of dynamic quantities with methods of digital signal processing and artificial intelligence.

Achieving such a formulated objective required, among other things, using measurement data acquired during active diagnostic experiments, investigating the suitability of various digital signal processing techniques for extracting key information, assessing the accuracy of malfunction qualification by selected artificial intelligence tools.

Using the measurement and processing module developed by the PhD candidate, vibrations of a passenger car engine without damage and with a defective ignition system were recorded; the experiments were performed at various loads and several rotational speeds. The experimental data base used to verify the effectiveness of the analysed diagnostic techniques was extended with time courses of rolling bearing vibrations made available by an American research centre.

Simulation studies carried out on processed experimental data have demonstrated the usefulness of artificial intelligence tools for diagnosing fault conditions in the ignition system of a car engine.

The work was concluded with a correct summary and indication of development directions; the usefulness of low-cost measurement and processing modules with MEMS accelerometers for vehicle diagnostics was emphasised.

The aim of the dissertation has been realised, and the developed methodology has a utilitarian significance, being a contribution to the development of engineering and technical sciences.

I evaluate the activities presented in the dissertation positively in terms of content and methodology. The author has correctly implemented the literature research, developed the vibration acquisition module, properly planned and executed the bench experiments and numerical simulations leading to the achievement of the work objective. He presented an interesting approach to artificial intelligence-supported digital signal processing, and the results of the research should improve the solution of specific engineering tasks in the area of automotive diagnostics.

4. Detailed critical remarks

The following questions and comments arise while reading the paper:

- To what extent can the solution of diagnostic problems of other vehicle faults be inferred from the effectiveness of tools identifying an uncomplicated fault in the ignition system of an internal combustion engine?
- How was measurement consistency ensured during calibration of the vibration acceleration recording set?
- For what purpose was the vibration signal sampled at 88240 Hz if the linear processing range of the accelerometer does not exceed 11 kHz?
- How are the dimensions of the rolling bearing components given in Table C1 to be understood? Why is the bearing load expressed in non-SI units?
- What was the rationale for not estimating the uncertainty of the experimental results? Is the uncertainty of the measurements important for the correct identification of faults?

5. Notes on the editing of the dissertation

From an editorial point of view, the dissertation is quite neatly prepared; however, the inconsistent description of the axes with the correct units (or the lack of a reference level for the decibel scale) and the small font size make the interpretation of some of the graphs difficult.

The author has not protected the work from minor editorial shortcomings, two examples below:

- The caption of Figure 1.1 illustrating the saturation of European countries with vehicles incorrectly refers to the volume of vehicle production in those countries;
- The integration interval in the definition of the effective value on page 8 is imprecisely given (it should be 0 to T instead of T_1 to T_2).

The shortcomings highlighted do not hinder the perception of the essence of the work.

6. Final conclusions

The critical remarks I have mentioned do not lower the positive overall assessment of the work. I believe that the dissertation presented for review is valuable in terms of cognitive and utilitarian aspects, and contains a novel perspective on the artificial intelligence-supported diagnosis of vehicle faults on the basis of a digitally processed vibration signal.

Muhammad Ahsan, MSc, has demonstrated his ability to formulate and independently solve the scientific problem of developing a methodology for vibration-based fault diagnosis of a car engine ignition system. He properly planned a series of bench and simulation tests and used the results obtained to correctly formulate conclusions. The PhD candidate has demonstrated that he has sufficient theoretical knowledge and practical skills in the discipline of Automation, Electronics, Electrical Engineering and Space Technologies, and that he is able to conduct scientific work independently.

Taking the above into account, I conclude that the reviewed doctoral dissertation of Muhammad Ahsan, MSc, "Vehicle Diagnostics using Artificial Intelligence and Digital Signal Processing Methods" meets the requirements for doctoral theses by the Law of 20 July 2018. Law on Higher Education and Science (Journal of Laws 2018, item 1668, as amended) and may be admitted to public defence.

[signed]: Grzegorz Klekot