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## SOFTWARE QUALITY MODEL FOR TUNING THE CLASS OF POLYHARMONIC ACOUSTIC SIGNAL GENERATION SYSTEMS

*Abstract.* The paper addresses the problem of software quality evaluation for automated professional tuning of acoustic string musical instruments. It is shown that modern approaches to software quality assurance are mainly based on the ISO/IEC 25000 SQuaRE series of standards. However, the basic ISO/IEC 25010 quality model does not fully consider the specific features of software intended for the analysis of polyharmonic acoustic signals and professional musical instrument tuning. An analysis of recent studies in the field of software quality modeling, assessment and evaluation has been conducted, demonstrating a transition from universal quality models to domain-oriented structures that incorporate specialized characteristics, metrics, and evaluation procedures. The purpose of the study is to extend the ISO/IEC 25010 product quality model in order to enable quality evaluation of software for tuning acoustic string musical instruments. Within the research, the performance efficiency characteristic of the ISO/IEC 25010 quality model has been extended by introducing domain-specific attributes adapted to the requirements of automated tuning of acoustic string musical instruments. The proposed extension supplements the standard attribute structure with the additional accuracy and precision attributes, while preserving compatibility with the original quality model. The obtained results provide a foundation for the further formalized development of procedures for software quality measurement and evaluation in the field of automated professional tuning

of acoustic string musical instruments, as well as for the creation of corresponding metric systems and software quality evaluation tools.

*Keywords*: software quality, ISO/IEC 25010, SQuaRE, tuning of musical instruments, acoustic signals.

*Problem statement.* Software quality assurance (SQA) is a critical component of modern software engineering, encompassing a set of processes, methods, and tools aimed at ensuring software products meet established quality standards, stakeholder requirements, and industry regulations throughout the development lifecycle. The importance of SQA stems from the fact that modern software underpins critical sectors such as finance, medicine, transportation, industry, and cybersecurity, and errors in such systems can lead to significant financial losses, data leaks, infrastructure disruptions, and threats to human safety. Furthermore, effective software reduces defect-fixing costs, reduces technical debt, improves the reliability, security, and competitiveness of software, and ensures the stability and predictability of development processes [1-3].

Systems for generating polyharmonic acoustic signals include the class of acoustic string musical instruments (ASMIs), which is thoroughly examined in the current study. One way to optimize this class of systems is to adjust the string tension to achieve an optimal, mathematically defined pitch ratio of the sound system (musical scale), which is therefore implemented as a tuning process. At the same time, a thorough analysis of the domain and directly related scientific research, a study of the historical development of tuning tools, an examination of the functionality of existing mobile software, and a summary of expert assessments of such tools [4-7] have revealed a contradiction between the need to improve the quality of software for tuning ASMIs in accordance with the high demands of specialist users.

In this situation, it is advisable to turn to the ISO/IEC 25000 SQuaRE series of standards [8], which is a generally recognized framework for defining, measuring, and evaluating software quality. At the same time, despite its conceptual completeness, the basic quality model proves insufficiently adequate for software designed for tuning ASMIs, as it does not fully define and formalize a number of quality attributes important for this domain, particularly those related to acoustic factors.

*Analysis of recent research and publications*. Modern research clearly demonstrates the transition from a general understanding of quality to an instrumental, metric-driven approach. In [9], a software tool for determining software quality using metric analysis methods was proposed, which emphasized the problem of the lack of unified standards for metrics and the complexity of interpreting their values. This direction was deepened through the formalization of the assessment procedure based on ISO/IEC 25010 and ISO/IEC 25023 [10], through the direct combination of quality model, indicators and metrics as the basis for measurement [11] and through the construction of a comprehensive assessment system, where quality is presented as a structured system of characteristics and attributes taking into account the cost of transition between quality states [12]. Another notable line of development is the multi-criteria ranking of ISO model characteristics for specific classes of software systems. In [13], the lack of established evaluation procedures and excessive subjectivity were directly indicated for the complexes of fire control automation tools of artillery units, after which new metrics, elements of their evaluation and the application of the method of hierarchy analysis were proposed to determine priorities at all levels of the hierarchy. In [14], the same approach was developed in the model of giving advantages to the characteristics of the software through the utility function, interpolation of tabular functions and a three-parameter hierarchical structure of criteria. At the same time, in the system of

comprehensive software quality assessment, it was emphasized that characteristics such as maintainability, portability, security, compatibility, reliability, ease of use and functional suitability should be included in multi-criteria optimization [12].

A separate direction of modern work is the evaluation of quality-in-use, which is based on user experience and the results of the system in a real context, and not only on technical specifications. In [15], a process model for software quality assessment was tested and the relationship between performance measurement and the detection of performance issues was shown, as they reflect the perceived quality of the system by the user. In [16], it was also proposed to extend ISO/IEC 25010 by adding information quality, learnability, actual usability and user experience, and to build an integrated flexible framework for modeling quality requirements and evaluating web applications. In [17], SQuaRE was applied to assess quality during the use of the online system “e-Ebola Awareness System”, which made it possible to identify problems that reduce the perceived quality of the portal. Finally, in [18], the FAQuiS framework for context-sensitive software systems was proposed, which combines model descriptions, log data, probabilistic models, heuristic metrics, clustering and feature selection. An equally important application of SQuaRE is seen in works on data quality. In [19], it was shown that data quality certification based on ISO/IEC 25012, 25024 and 25040 in three European organizations increases trust in data and helps to understand business processes more deeply. The authors of [29] proposed a prototype tool based on ISO/IEC 25012 and ISO/IEC 25024, which analyzes typical error patterns in data and allows to judge their current state. In [21], a framework for assessing data cybersecurity was developed, where the characteristics of conformity, confidentiality, traceability, availability and recoverability were borrowed from ISO/IEC 25012, the corresponding properties and basic metrics from ISO/IEC 25024, and the assessment process

itself was adapted from ISO/IEC 25040. This demonstrates the trend towards adapting SQuaRE to assess new aspects related to data quality.

In applied domains, SQuaRE is increasingly becoming a basis that is further adapted to the specifics of a particular field. In [22], the ISO/IEC 25010 model was used to evaluate a system for monitoring and predicting the scientific productivity of teachers. In [23], it was used to evaluate Building Information Modelling (BIM) tools for landscape design in climate adaptation. A systematic review of quality models for AI systems, software, and components [24] showed that most quality models for AI are actually extensions of the traditional ISO/IEC 25010, and for AI software components, the study did not find established quality models. This once again confirms that the basic ISO model is sufficient for a general "framework", but for specialized systems it requires domain adaptation by introducing additional characteristics and attributes that reflect the specific requirements of the relevant domain.

Summarizing the studies considered, it can be concluded that modern approaches to modeling and assessing software quality are developing in the direction of transition from static universal solutions to flexible subject-oriented structures. This makes it possible to adapt models and methods of SQA to the features of specific classes of software systems and their operating conditions, in particular, software for configuring the class of polyharmonic acoustic signal generation systems.

*Purpose of the article*

To expand the software quality model SQuaRE to provide the possibility of evaluating the effectiveness of automated professional tuning tools for ASMIs. To achieve this goal, it is necessary to consider the basic quality model of the product, its purpose and components, and to form new elements of the model adapted to the specifics of the domain.

*Presentation of the main material of the study*

Polyharmonic acoustic signal generation systems are objects or complexes that are capable of simultaneously creating and emitting sound waves consisting of many frequency components – harmonics (partials). They combine an energy source, a vibration excitation mechanism and a resonator, which allows forming a complex, rich spectral composition of sound. Such systems are widely used in a wide variety of areas, whether it is advanced industrial production or the creation and performance of musical works.

Among the technical examples, one can single out specialized industrial acoustic vibration generators, hydroacoustic stations, ultrasonic material control systems, as well as digital sound synthesizers and multi-channel audio systems. At the same time, there are also non-technical systems, a vivid example of which are ASMIs, or chordophones, where the source of the polyharmonic signal is the vibration of strings amplified by a resonator body. The study of this class of systems requires special attention and detailed analysis. This is primarily due to the high complexity and specific features of the process of their tuning, where even minimal changes in parameters significantly affect the final spectrum of the emitted sound.

According to the SQuaRE series of standards, the software product quality model (SPQM) is a reference structure that defines a set of characteristics and subcharacteristics intended for specifying quality requirements, their measurement and evaluation throughout the software life cycle. The model is domain-independent and can be applied to a wide range of software and information and communication products. Therefore, it provides a general system of quality characteristics that can serve as the basis for developing specialized quality models adapted to the features of a particular class of software systems.

The proposed SPQM for automated tuning of ASMIs is based on this reference model while taking into account the specifics of polyharmonic acoustic signal analysis and the musical instrument tuning process. This approach

preserves compatibility with the ISO/IEC 25010:2023 product quality model while adapting the performance efficiency characteristic to the requirements of the application domain.

Formally, the quality model can be represented as a set of characteristics

$$SPQM = \langle Ch_{FuncSuit}, Ch_{PerfEff}, Ch_{Comp}, Ch_{IntCap}, Ch_{Rel}, Ch_{Sec}, Ch_{Main}, Ch_{Flex}, Ch_{Saf} \rangle,$$

where each quality characteristic is defined by a tuple

$$Ch_i = \langle Name_i, Def_i, Attr_i \rangle,$$

where $Name_i$ is the name of the characteristic;

$Def_i$ is its definition according to ISO/IEC 25010:2023;

$Attr_i$ is a set of attributes (sub-characteristics) that detail the corresponding characteristic.

In the proposed model, the quality characteristics defined by the ISO/IEC 25010:2023 standard are used as the basic structure of the model without changing their composition. However, the performance efficiency characteristic ($Ch_{PerfEff}$) is extended by introducing an additional set of attributes, taking into account the features of the software for automated tuning of ASMIs. The need for such an expansion is due to the fact that standard attributes characterize the efficiency of the software product mainly in terms of execution time, use of computing resources, and system capacity under given operating conditions. Thus, this characteristic is focused primarily on assessing the efficiency of hardware resource use and software execution performance, while in tuning tasks the ability of the software to provide a high-quality result of the analysis of polyharmonic acoustic signals and the tuning process itself is no less important.

For the user of such software, efficiency is determined not only by the speed of operation or the use of computing resources, but primarily by how correctly and

stably a software tool determines the parameters of the polyharmonic acoustic signal and how quickly it provides a result that is accurate enough to perform the tuning. In other words, during the external evaluation of a software as a “black box”, the determining value is not the internal implementation of algorithms, but the ability of a software tool to provide a high-quality tuning result under various operating conditions. The higher the software efficiency, the closer the result of automated tuning is to the target state of an instrument, and therefore, the less effort and time it takes for a tuner to finalize it.

In view of this, it is advisable to supplement the standard attributes of the performance efficiency characteristic with domain-specific attributes of accuracy and precision, which directly characterize the correctness and repeatability of the results of the analysis of polyharmonic acoustic signals and the tuning process. At the same time, the time behavior attribute, defined by the ISO/IEC 25010:2023 standard, is retained unchanged and is used to evaluate the time characteristics of the software, in particular the speed of determining the signal parameters and the speed of performing the tuning process. Thus, the performance efficiency characteristic is expanded without violating its basic structure, which ensures compatibility of the developed model with the ISO/IEC 25010:2023 standard and at the same time takes into account the specifics of tuning software.

After justifying the need to expand the performance efficiency characteristic, the quality model of software for automated tuning of ASMIs can be formally presented as

$$SPQM^{*} = \langle Ch_{FuncSuit}, Ch^{*}_{PerfEff}, Ch_{Comp}, Ch_{IntCap}, Ch_{Rel}, Ch_{Sec}, Ch_{Main}, Ch_{Flex}, Ch_{Saf} \rangle,$$

$$Ch^{*}_{PerfEff} = \langle Name_{PerfEff}, Def^{*}_{PerfEff}, Attr^{*}_{PerfEff} \rangle,$$

where $Ch^{*}_{PerfEff}$ is an extended performance efficiency characteristic, and the other characteristics correspond to the quality model defined by the ISO/IEC 25010:2023 standard;

$Name_{PerfEff}$ = “performance efficiency” – a characteristic name (the same);

$Def^{*}_{PerfEff}$ = “capability of a product to perform its functions within specified time and throughput parameters and be efficient in the use of resources, and achieve the required level of accuracy and precision of the produced results under specified conditions” – a characteristic definition (modified);

$Attr_{PerfEff} = \langle Attr_{TimeBeh}, Attr_{ResUtil}, Attr_{Cap} \rangle$ – performance efficiency attributes in the basic software quality model;

$Attr^{*}_{PerfEff} = Attr_{PerfEff} \frown \langle Attr_{Acc}, Attr_{Prec} \rangle$ – the extending performance efficiency attributes with accuracy ($Attr_{Acc}$) and precision ($Attr_{Prec}$) respectively;

$\frown$ is an operator that denotes the concatenation of two tuples.

Thus, the proposed extension does not change the structure of the basic quality model ISO/IEC 25010:2023, but only supplements the performance efficiency characteristic with attributes that reflect the specifics of the software for automated tuning of ASMIs. Due to this, the model maintains compatibility with the international standard, while providing the possibility of a more complete evaluation of the software efficiency from the end user's perspective.

*Conclusions*

In this paper, a software product quality model for automated professional tuning of acoustic string musical instruments is improved by extending the basic ISO/IEC 25010 model through the refinement of the efficiency characteristic and the introduction of additional quality attributes that reflect the specifics of polyharmonic acoustic signal analysis and the tuning process. The proposed model provides a foundation for the formalization of efficiency requirements for tuning software. Combined with the developed mathematical models of the ASMI and its tuning, it enables the definition of formalized procedures for

measuring, evaluating, and comparing the quality of tuning software based on a system of metrics and evaluation criteria.

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