Advances in Educational Technology and Psychology (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/aetp.2024.080627
ISSN 2371-9400 Vol. 8 Num. 6

Development of a Teaching Case Library for Modern Testing Techniques and Applications Targeted at Professional Degree Graduate Students

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Keywords: Modern Testing Techniques and Applications, Case Library, Professional Degree Graduate Students

Abstract: To address the limitations in the teaching cases of the "Modern Testing Techniques and Applications" course, which often focus on isolated knowledge points and outdated application contexts, this paper develops a comprehensive case library. The library compiles cases from the forefront of engineering testing research, industrial production practices, and the research outcomes of project team members. It is tailored for graduate students in mechanical engineering, integrating practical engineering applications, cutting-edge academic research, and broad content coverage. Furthermore, this paper examines the implementation process, teaching format, and key features of case-based instruction. Through this approach, students can gain insights into the latest advancements in the field, engage with real-world industrial practices, and enhance their engineering skills and innovation capabilities.

1. Introduction

"Modern Testing Techniques and Applications" is a specialized course offered to master's degree students in Mechanical Engineering at our university. The course emphasizes its close connection to engineering practice and integrates multidisciplinary knowledge from areas such as mechanics, sensing, electrical and electronic engineering, control technology, physics, and engineering mathematics. It features interdisciplinary integration, comprehensive knowledge across various fields, and abstract theoretical concepts that are challenging to grasp. This necessitates instructors to move beyond mere recitation of textbook knowledge and to incorporate practical engineering examples to enhance students' ability to address complex engineering problems. In 2015, the Ministry of Education issued the "Opinions on Strengthening Case Teaching and Joint Training Base Construction for Professional Degree Graduate Students," which explicitly states that "case teaching is an essential method for promoting the reform of professional degree graduate student training models." Consequently, in classroom instruction, we have adopted case-based teaching methods to simulate real-world engineering scenarios[1]. This approach encourages students to actively think, analyze, and discuss using their acquired knowledge, while also fostering continuous interaction and exchange between teachers and students to identify optimal solutions to practical problems. The ultimate goal is to enhance students' problem-solving and analytical skills.

Research on teaching cases for testing technology courses in mechanical engineering remains limited both domestically and internationally. Existing case libraries primarily target undergraduate and associate degree levels, with few studies focusing on professional degree graduate students. While some instructors have incorporated engineering examples to enrich their teaching, these examples often fall short of meeting the criteria for effective teaching cases. For instance, they typically cover single knowledge points and lack connections to related concepts, comprehensiveness, and systematicness. Many teaching cases are theory-based and disconnected from actual engineering practices and specific professional contexts. Given the rapid advancement of new principles and technologies in testing techniques[2], course content must stay current with the latest developments in the field. However, many existing cases are outdated, failing to reflect recent technological advancements. Consequently, the full potential of well-designed teaching cases is not realized, hindering the development of graduate students' abilities in problem analysis, practical skills, and innovation.

Clearly, compared to the urgent need for case-based instruction in testing technology courses for professional degree graduate students in mechanical engineering, the development of teaching case libraries has significantly lagged behind. To ensure the smooth implementation of case-based teaching, it is crucial to strengthen graduate students' systematic understanding of theoretical knowledge, enhance their ability to analyze and solve practical problems, and inspire innovative thinking. Therefore, the construction and improvement of a teaching case library that aligns with the characteristics of testing technology courses is of great importance.

2. Content and Format Standards for the Case Library

2.1. Architecture of the Case Library

In alignment with the educational objectives for the professional degree graduate course "Modern Testing Technologies and Applications" in mechanical engineering, and in conjunction with current engineering practices and research hotspots in the field, we have developed and refined a case library for this course. The case library includes 10 cases sourced from the cutting edge of academic research in mechanical engineering, practical experiences in industrial production, and relevant scientific research achievements of the project team members. These cases are characterized by their novelty, comprehensiveness, and strong practical applicability, supported by a rich array of illustrative images and detailed data. The content of the cases covers key topics such as signal analysis and processing, fault diagnosis, and the setup of testing systems, effectively addressing the core and challenging aspects of the course curriculum. The cases are categorized into three types—foundational, comprehensive, and frontier—to cater to different teaching content. The architectural structure of the "Modern Testing Technologies and Applications" course case library is illustrated in Figure 1.

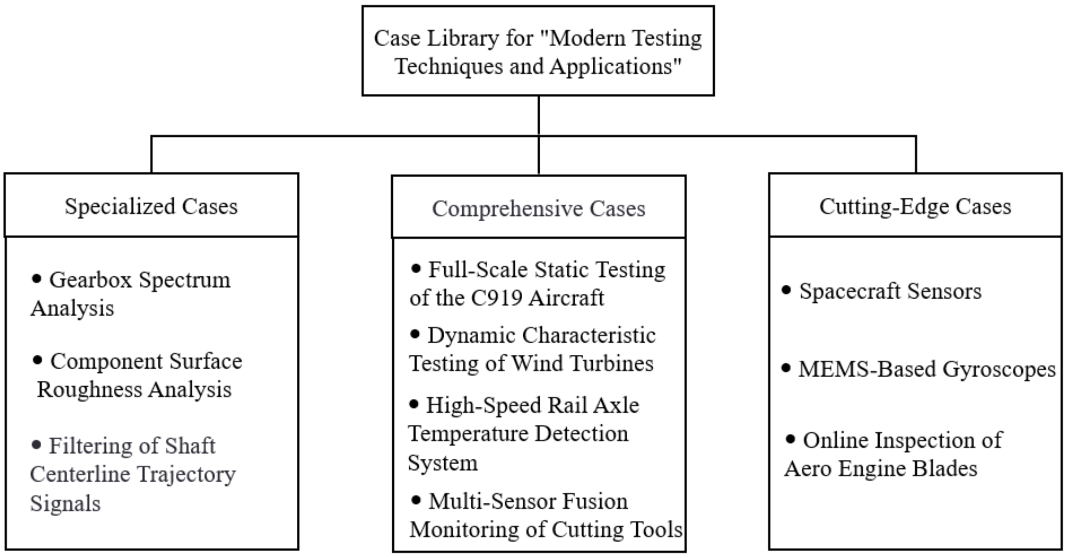


Figure 1: Case Library Architecture.

The project team members have extensive research experience in mechatronic system design and motion control, high-speed cutting processes, and intelligent manufacturing. Integrating some of the research outcomes from these faculty members into the teaching cases of the course "Modern Testing Techniques and Applications" can facilitate a positive interaction between research and education.

2.2. Case Format Specifications

To reflect the systematic, inspirational, interactive, and practical nature of case-based teaching, we have established scientific and reasonable case format specifications, including the introduction of background, presentation of problems, introduction of key concepts, analysis of problems, and drawing conclusions. Additionally, a variety of rich and vivid case presentation formats have been designed to enhance teaching effectiveness, improve students' theoretical knowledge, and enhance their ability to solve practical problems.

3. Innovative Aspects of Case Library Development

The teaching case library developed for the course "Modern Testing Techniques and Applications" has the following distinctive features and innovations:

(1) Integration of Engineering Practice and Academic Frontiers

The case library draws materials from engineering practices, prominent academic achievements closely linked to engineering, and relevant research topics of the project team members. Additionally, external experts with extensive engineering experience have been invited to participate in the development of the cases. The emphasis is on integrating engineering practice and academic frontiers. This approach not only significantly enhances students' ability to apply theoretical knowledge to solve complex engineering problems but also keeps them informed about the latest research developments, thereby broadening their academic horizons.

(2) Combination of Specialized and Comprehensive Cases

The case library comprises both specialized and comprehensive cases. Specialized cases are designed to highlight a series of concentrated and related knowledge points, thereby reinforcing students' understanding of theoretical concepts. Comprehensive cases, on the other hand, emphasize the horizontal and vertical connections between knowledge points, often spanning multiple chapters.

This approach is beneficial for enhancing students' ability to integrate and apply theoretical knowledge to solve complex engineering problems.

(3) Integration of Classroom Teaching and Project Design

The comprehensive cases in this case library encompass the characteristic analysis of the object being tested, the selection of relevant testing components, the development of testing systems, and signal analysis and processing. These cases are marked by their complexity and comprehensiveness. The theoretical knowledge required for these cases is introduced during class through an interactive, question-based teaching approach, guiding students to think about applying the relevant knowledge to solve the engineering problems presented in the cases. Tasks such as researching materials, determining the types and models of testing components, and setting up the testing platform are completed by students as part of project design work outside of class. Students present their design results in the next class session, followed by feedback and summarization from the instructor. The integration of classroom teaching and project design in case-based teaching not only deepens students' understanding of theoretical knowledge but also enhances their ability to analyze and solve practical engineering problems.

4. Typical Case Analysis

Case Name: Multi-Sensor Fusion for Monitoring Tool Wear.

Background Introduction:

Cutting tools, often referred to as the "teeth" of machine tools, play a crucial role in ensuring the stability, efficiency, and quality of the machining process. Consequently, timely, accurate, and reliable assessment of tool condition has become an important research topic.

Problem Statement:

To detect the cutting state of the tool, appropriate sensors and signal acquisition devices must be selected and installed, and a tool wear monitoring system must be set up.

Introduction to Key Concepts:

To achieve real-time and proactive monitoring of tool wear, it is necessary to use sensors to collect multi-source and heterogeneous data generated during tool operation. Tool wear increases the friction force between the tool and the workpiece, leading to an increase in cutting force. Simultaneously, the time-domain characteristics of vibration signals exhibit a clear upward trend as tool wear progresses. Additionally, tool wear can cause acoustic emission phenomena, with acoustic emission signals having higher frequencies that are distinct from the frequency bands of process system vibrations and other interference signals. Therefore, the monitoring system selects cutting force signals, vibration signals, and acoustic emission signals as key indicators for tool condition monitoring.

Case Analysis:

When setting up the signal acquisition system, the selection and installation positions of the sensors significantly affect the accuracy of signal collection and processing. First, the sensors' sensitivity, response characteristics, and precision must align with the current machining conditions and experimental objectives. Second, the sensors must be installed at appropriate measurement locations.

(1) Selection of Sensors

(a) Kistler 9129AA Triaxial Cutting Force Sensor. (b) Kistler 8763B050BB Triaxial Vibration Sensor.

(c) Kistler 8152C0050502 Acoustic Emission Sensor (d) 5152C Signal Conditioner

Figure 2: Various Types of Sensors and Signal Conditioners.

1) Cutting Force Sensor

a) Sensor Name: Kistler 9129AA Triaxial Cutting Force Sensor (as shown in Figure 2(a)). This triaxial cutting force sensor, manufactured by Kistler of Switzerland, offers high stiffness, high natural frequency, and low hysteresis. It is suitable for online measurement of dynamic cutting

b) Main Technical Parameters of the Sensor: the force measurement range in the X, Y, and Z directions is -10 to 10 kN; the sensitivity in the X and Z directions is -8.1 pc/N, while the sensitivity in the Y direction is -4.1 pc/N.

2) Vibration Sensor

a) Sensor Name: Kistler 8763B050BB Triaxial Vibration Sensor (as shown in Figure 2(b)).

b) Main Technical Parameters: the measurement range is ±50g, the sensitivity is 100 ±15% mv/g, and the frequency range is 0.3 to 10kHz.

3) Acoustic Emission Sensor and Signal Conditioner

a) Sensor Name: Kistler 8152C0050502 Acoustic Emission Sensor (as shown in Figure 2(c)). This sensor has high sensitivity and a wide frequency range, and it is insensitive to electrical noise and magnetic fields. Additionally, the device is compact and can be easily installed near the acoustic emission source.

b) Main Technical Parameters: frequency range is 50~400 kHz, sensitivity is 57 dBref 1V/(m/s).

c) Signal Conditioner

Since the acoustic emission sensor requires power to function properly, the Kistler 5152C Signal Conditioner (as shown in Figure 2(d)) is selected. This instrument offers two gain settings: 10 dB and 100 dB, and it includes a high-pass filter at 50 kHz and a low-pass filter at 1 MHz.

d) Signal Acquisition Equipment

(a) HRU-1213MA Data Acquisition Device (b) 5165A Data Acquisition Device

Figure 3: Signal Acquisition Device.

The cutting force signal acquisition device (as shown in Figure 3(a)) is the HRU-1213MA 10-channel data acquisition device produced by Shanghai Hona Electronics Technology. Each channel has a sampling rate ranging from 0 to 100 kHz and a resolution of 16 bits. The vibration and acoustic emission signals are acquired using the Kistler 5165A 4-channel data acquisition device (as shown in Figure 3(b)). Each channel of this device has a sampling rate ranging from 0 to 200 kHz and a resolution of 24 bits.

(2) Installation of Sensors

The installation positions of the sensors are shown in Figure 4: the triaxial force sensor is mounted beneath the tool holder, the triaxial vibration sensor is positioned above the tool holder near the cutting edge, and the acoustic emission sensor is placed on the right side of the tool holder, also close to the cutting edge.

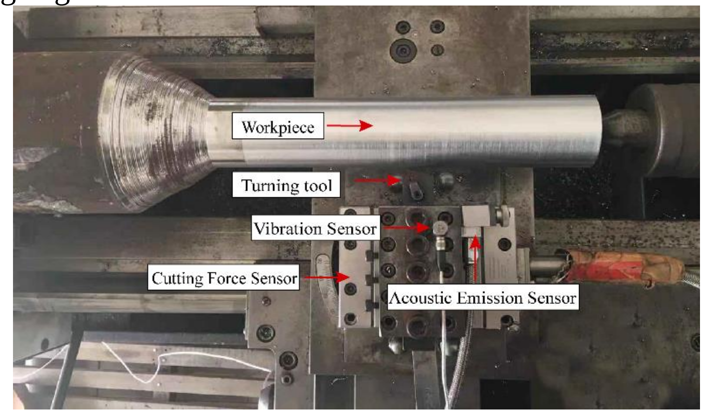
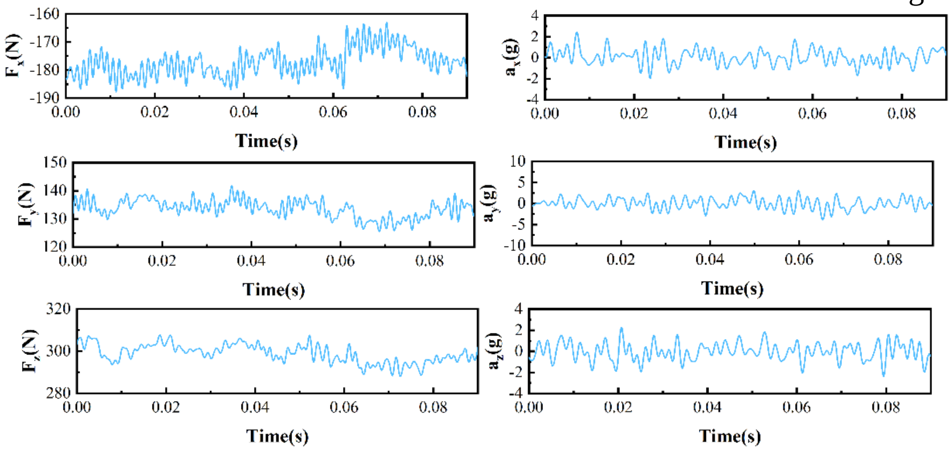
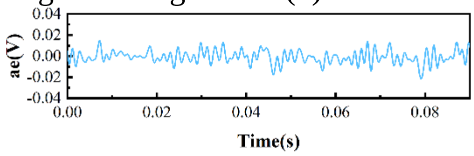


Figure 4: Sensor Installation Positions [3].

Turning of a 45 steel rod was performed using a tungsten carbide tool. The cutting parameters were as follows: cutting speed v=200m/min, feed rate f=0.198mm/r, and depth of cut a_p=0.5mm. During the turning process, triaxial cutting force signals (F_x, F_y, F_z), triaxial vibration signals (a_x, a_y, a_z), and acoustic emission signal a_e were collected with a sampling frequency of 50 kHz. The time-domain signals from the sensors when the flank wear VB=0.084mm are shown in Figure 5.



(a) Cutting Force Signals. (b) Vibration Signals.



(c) Acoustic Emission Signals.

Figure 5: Time-Domain Signals during Cutting of 45 Steel (Flank Wear VB=0.084 mm).

5. Conclusions

Based on the characteristics of tool wear, the selection and installation of vibration sensors, acoustic emission sensors, and signal acquisition devices were conducted. This process aimed to train students in the deep understanding and application of both static and dynamic properties of sensors, as well as their ability to set up experimental platforms.

By analyzing the relevant characteristics of vibration and acoustic emission signals at different stages of tool wear, we further explore the advantages of multi-sensor fusion in monitoring tool wear. Under complex and variable cutting conditions, the information provided by a single sensor is limited and susceptible to external environmental influences, making it difficult to comprehensively and accurately reflect the changes in the tool wear state during the cutting process. Multi-sensor signal fusion can complement the strengths of various sensor signals, enhancing interference resistance and better reflecting the characteristic changes in the cutting process. However, increasing the number of sensors in multi-sensor fusion is not always beneficial. An excessive number of sensors can lead to increased redundant information, which is detrimental to subsequent signal processing [4].

6. Implementation Results

The case studies developed in this project have been integrated into the curriculum of the "Modern Testing Techniques and Applications" course for mechanical engineering graduate students from the 2021 and 2022 cohorts. The teaching approach combines lectures, heuristic questioning, and group discussions, along with a blend of classroom instruction and project-based learning. This diverse array of instructional methods has facilitated the mastery of theoretical knowledge, honed students' abilities to analyze and solve complex problems, and enhanced overall educational outcomes. Several students have reported that this course has helped them build a solid foundation in essential skills, such as setting up testing platforms and analyzing and processing signal data, which are crucial for their research endeavors.

Through the case-based teaching of "Modern Testing Techniques and Applications," which integrates engineering practicality, academic cutting-edge research, and comprehensive coverage, students gain insights into the latest developments in the field, experience real-world industrial production, and reinforce their foundational knowledge while solving case problems. This approach enhances their practical skills and fosters innovation awareness.

Acknowledgements

The author sincerely thanks the following projects for their support of this research: Postgraduate Educational Teaching Reform Research Project of Shandong Province (SDYJSJGC2023063), Postgraduate Educational Teaching Reform Project of Qilu University of Technology (YJG23ZD004, YJG23YB004), Quality Educational Resources Project for Postgraduate Education of Shandong Province (SDYAL2023146).

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