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Fully Automated Paper Document Sorting Robot Design

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Abstract: A fully automated paper document sorting robot was developed in this project. This robot classifies documents efficiently and accurately. The objective of this project was to improve the efficiency of classifying or sorting paper documents, reduce costs, and save time. The robot can classify documents according to user-defined rules, such as keywords, dates, serial numbers, bar codes, and the meaning of paragraphs. Since it can classify or sort documents intelligently, it can complete large-scale document classification quickly. The robot is constructed using an aluminum profile to create a box-type truss gantry structure frame. It was built on the LubanCat 4 motherboard and controlled through Python language programming. Driven by a stepper motor to move the manipulator. The camera module is combined with an artificial intelligence algorithm to recognize paper in real time, and the text is recognized after taking pictures of the paper. The sorting function is performed by several sensors. In addition, a web-based human-computer interaction platform was developed using the Flask web framework in Python. Users could access this platform in a variety of ways, allowing them to easily and swiftly configure parameters and send operational instructions to perform various functions.

Keywords: Paper documents; Sorting robot; Python; Human-computer interaction

Online publication: November 29, 2023

1. Introduction

Paper document sorting is done manually in many offices. Manual paper sorting not only requires a huge amount of manpower and material resources, but it is also not efficient and precise. Therefore, the use of robots has been a development trend in offices in various countries [1], and there have been several studies in this field. For example, automatic cigarette paper sorting and packaging equipment has been developed, which is composed of a conveying system, a palletizing system, a belt system, etc [2]. An intelligent sorting system for express packages based on barcode recognition has also been developed [3]. An automatic sorting system of material flow has been developed to reduce coordinate deviation and logistics sorting error rate of items captured by the existing system, and the system showed good results [4]. A robot capable of handling multiple items has been developed. This robot employs deep learning object detection and a 3D vision algorithm to guide the robot arm in grasping, classifying, and placing items. The primary objective of this research is to address challenges related to identifying irregular multi-items within cluttered and disorganized piles [5]. Moreover, a coin sorting and counting control system has also been designed to reduce the burden of manual coin counting and sorting and human errors [6]. In addition, a 3D printer based on a rectangular coordinate system has been developed, with a focus on optimizing the mechanical structure of the 3D printer for improved performance. Despite these advancements, there remains a relative scarcity of research in the area of paper sorting. Therefore, we developed a fully automatic paper-sorting robot.

2. Design scheme

In this project, we developed a fully automated paper document sorting robot, which was composed of hardware and software. To begin, the hardware components are constructed using aluminum profiles to create the framework in the form of a box truss gantry structure. This framework accommodates the installation of racks, linear guide rails, gears on the stepper motor, and rack clamps. These elements enable the slider on the linear guide rail to move along the X, Y, and Z axes, facilitating the three-dimensional movement of the manipulator. In addition, the mini vacuum pump is connected with the mini solenoid valve and the vacuum nozzle through a pneumatic tube, and the power supply of the mini solenoid valve is controlled by a relay to adsorb or release the paper. Secondly, the LubanCat 4 embedded development board is used as the motherboard of the electrical circuit. This board transmits pulse signals to stepper motor driver, driving the stepper motor. Additionally, a camera module is employed to identify the paper's position and capture images of the paper. A negative pressure sensor module is utilized to continuously monitor pressure levels in real-time, while a laser ranging module enables real-time measurement of the distance between the vacuum nozzle and the paper. Lastly, an artificial intelligence algorithm combined with a camera module is used to detect the position of the paper, identify the text on the paper, and build a human-computer interaction system based on the motherboard. Users can access the system through computers or mobile devices to control the sorting robot.

The operating procedure of the robot is as follows: The user selects the rules for classification or sorting in the human-computer interaction interface. After receiving the instruction, the motherboard coordinates various electrical circuits and drives the stepper motor to make the manipulator module reach the paper position. Then, the camera module identifies the content on the paper, the vacuum nozzle absorbs the corresponding paper, analyzes the content, and moves the paper to a specific position for release [8]. The overall structure of the sorting robot developed in this project is shown in **Figure 1**.

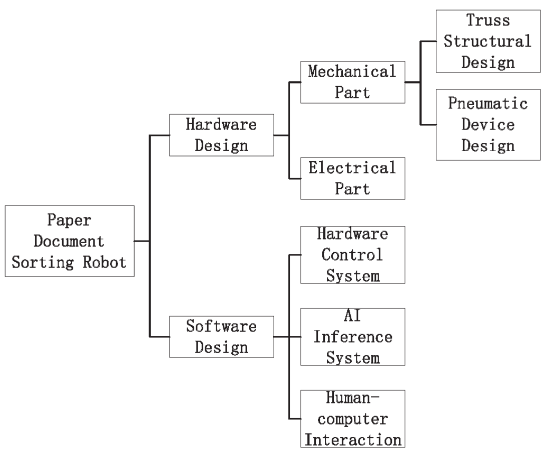

Figure 1. The overall structure of the sorting robot

3. Hardware design

The hardware design of this project was composed of mechanical part and electrical part. The mechanical part includes a truss structure design and pneumatic device, while the electrical part is composed of a LubanCat 4 embedded development board, truss structure control circuit, pneumatic device control circuit, manipulator module, etc. The manipulator module includes a camera module, a negative pressure sensor module, a laser ranging module, a micro switch, etc. Users can choose to connect with the motherboard by wired or wireless means, set parameters, and send operation instructions through the human-computer interaction interface. After receiving the instructions, the motherboard first instructs the camera to detect the position of the paper, controls the stepper motor on the X-axis and Y-axis to drive the mechanical structure, and runs the manipulator above the position of the paper. Then the camera and OCR model take a picture of the paper and identify the text. The Z-axis stepper motor then lowers the manipulator until the micro switch touches the surface of the paper document and triggers the stop signal. The solenoid valve is then opened so that the vacuum nozzle absorbs the paper and moves it to a specific position. Then, the solenoid valve closes to release the paper, completing the paper sorting task [9].

3.1. Mechanical part

3.1.1. Truss structural design

The mechanical structure of the paper document sorting robot developed in this project adopts a box-type truss gantry structure, which is built with European standard aluminum profiles and fixed with connectors and fasteners. Its structure is composed of three axes, X, Y, and Z, forming the space rectangular coordinate system. Its structure diagram is shown in **Figure 2**, AB and CD are the X-axes, EF is the Y-axis, and GH is the Z-axis. The X-axis is the horizontal axis of the truss structure, parallel to the ground and perpendicular to the Y-axis and Z-axis, which is used to control the left and right/lateral movement of the manipulator module. The Y-axis is the front and back axis of the truss structure, parallel to the ground and perpendicular to the X-axis and Z-axis, which is used to control the front and rear/longitudinal movement of the manipulator module. The Z-axis is the vertical axis of the truss structure, perpendicular to the ground, X-axis and Y-axis, which is used to control the up and down movement of the manipulator module. A rack and linear guide rails are installed on the X, Y, and Z axes, and a slider is installed on the linear guide rails. The X-axis sliders are connected with the Y-axis, and the Y-axis slider is connected with the Z-axis slider. The end of the Z-axis is connected with the manipulator, and the gear is installed on the output shaft of the three stepper motors, so that the gear is engaged with the rack. When the stepper motors rotate, the sliders can move on the X, Y, and Z axes. The truss gantry structure has the advantages of stable structure, large load-bearing capacity, and large free space.

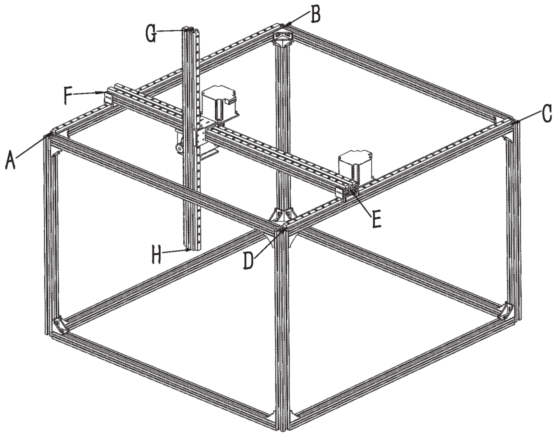

Figure 2. Truss structure diagram of sorting robot

The truss structure is driven by three stepper motors, as shown in **Figure 3**, and the transmission mechanism is composed of a gear, a rack, a linear guide rail, and a slider. The stepper motor can achieve very precise position control, with high torque and high stability, and its output shaft is connected to the gear, the gear is fastened to the rack on the aluminum profile, and the movement of the rack is controlled by the rotation of the gear, thus driving the movement of the truss structure. The linear guide rails are fixed on the aluminum profile, providing smooth and linear guidance and support for the truss structure. The sliders slide across the linear guide rails, allowing the truss structure to move along the linear track, while reducing friction and vibration, ensuring the precise position control and smooth movement.

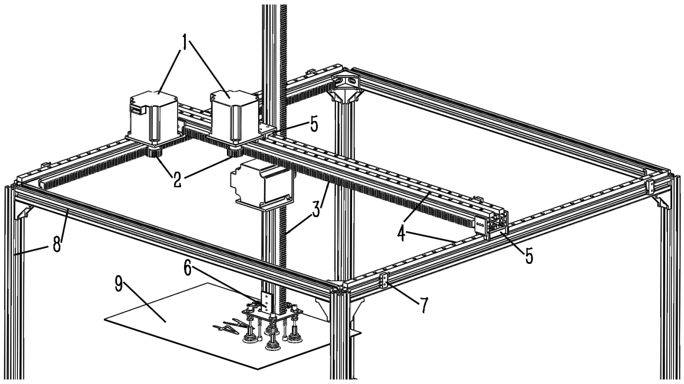

Figure 3. Assembly diagram of main parts of sorting robot. (1) Stepper motor, (2) Gear, (3)Rack, (4) Linear guide rail, (5) Slider, (6) Manipulator module, (7) Limit switch, (8) Aluminum profile, (9) Paper document

3.1.2. Pneumatic device design

The pneumatic device of this project is composed of a mini vacuum pump, a mini solenoid valve, a pneumatic tube, a vacuum nozzle, etc. A mini vacuum pump is utilized to create a negative pressure environment, and a mini solenoid valve is used to control the on-off of the air. The pneumatic tube is linked to the mini vacuum pump, the mini solenoid valve, and the vacuum nozzle for transmitting negative pressure, and the vacuum nozzle is responsible for generating the suction effect. The mini vacuum pump generates negative pressure, and the mini solenoid valve opens or closes accordingly. When it is necessary to adsorb paper, the mini solenoid valve opens, permitting the flow of air. The pneumatic tube transmits negative pressure from the mini vacuum pump to the mini solenoid valve, and then transmits it to the vacuum nozzle. The vacuum nozzle makes contact with the paper's surface and employs negative pressure to adsorb it. When it is time to release the paper, the mini solenoid valve is closed, stopping the flow of air. This action eliminates the negative pressure, causing the paper to be released. The flow chart of this process is shown in **Figure 4**.

3.2. Electrical part

3.2.1. Luban Cat 4 embedded development board

The Luban Cat 4 development board is used as the motherboard for this project due to its high performance. The system-on-a-chip model utilized is the Rockchip RK3588S, featuring four Cortex-A76 cores and four Cortex-A55 cores, along with MALI-G610 MC4 GPU cores, and operates at a main frequency of 2.4GHz. This configuration delivers 6Tops of computing power, effectively meeting the performance demands of the project's development and operational environments. Additionally, the board includes a 40PinGPIO pin, supporting a universal asynchronous receiver/transmitter, an inter-integrated circuit, a serial peripheral interface,a pulse width modulation, a USB-A interface, and an RJ45 Ethernet interface to fulfill the project's external hardware equipment requirements.

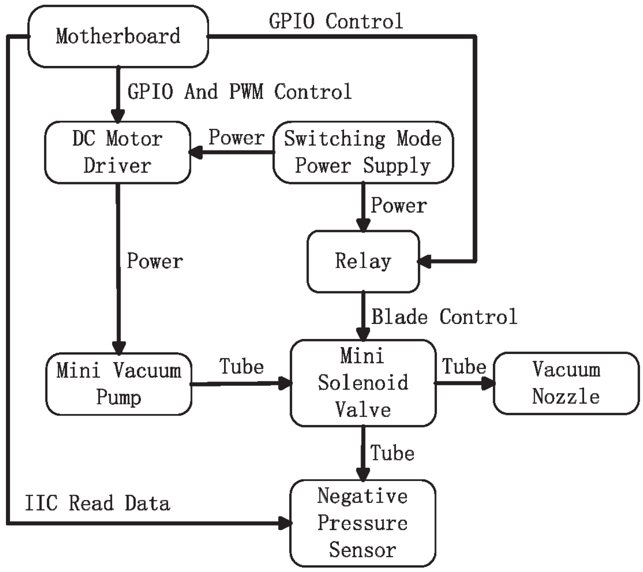

Figure 4. Design of pneumatic device

3.2.2. Truss structure control circuit

TB6600 stepper motor driver and 57BYG250B stepper motor are the power sources of the truss structure. Phase A and phase B of the stepper motor are connected to the driver respectively, and the control ENA, DIR, and PUL control pins of the driver are connected to the GPIO pins of the motherboard. The VCC and GND pins are connected to an external DC12V power supply, and the stepper motor can be enabled by writing a program to input a low level to the ENA+ pin. The forward or reverse of the motor is controlled by the DIR+ pin, and the PWM pulse signal can be sent to the PUL+ pin to control the motor rotation speed. The PWM waveform in a certain period, the greater the duty cycle, the faster the speed of the motor. Thus, different axes in the truss structure are controlled to move at different speeds and directions, and the connection of the truss structure control circuit is shown in **Figure 5**. As a trigger sensor, the limit switch is installed at both ends of the linear guide to limit the movement of the slider. The first is to ensure the operation accuracy and positioning accuracy of the machine. When the slider touches the limit switch, it sends a level signal to the GPIO pin of the main control board as an instruction to stop and align.

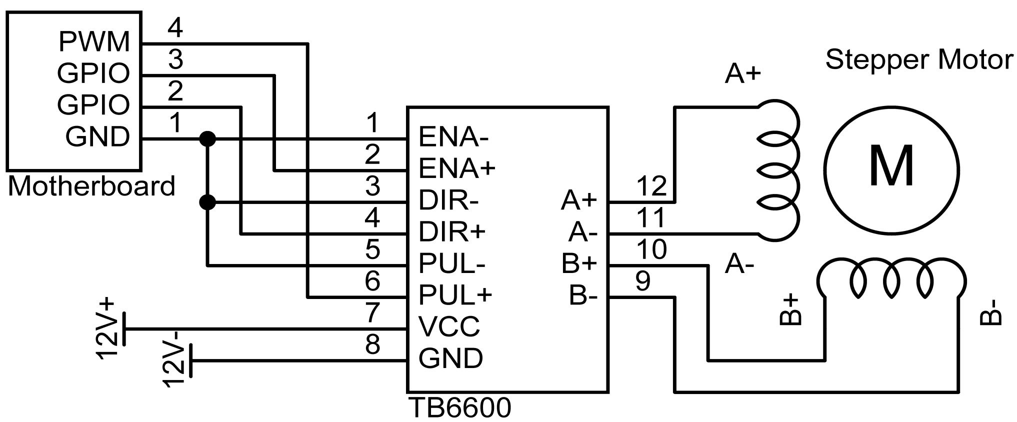

Figure 5. Truss structure control circuit connection diagram

3.2.3. Pneumatic device control circuit

The mini vacuum pump selected in this project has a DC12V DC motor built in, so the IC of model TA6586 is selected to drive the DC motor. The power supply of the DC12V mini solenoid valve is controlled by SRD-05VDC-SL-C relay. The control pin and relay of TA6586 are connected to the GPIO pin of the motherboard, as shown in **Figure 6**. The motherboard inputs PWM pulse signal to the BI pin of TA6586 and low level to the BF pin. The speed of the DC motor can change with the change of the PWM waveform, and the faster the speed, the stronger the suction of the mini vacuum pump. The common end of the relay is connected to the positive electrode of DC12V power supply, and one end of the mini solenoid valve is connected to the beginning of the relay, and the other end is connected to the negative electrode of DC12V power supply. When the GPIO pin output is low, the relay engagement and the mini solenoid valve is started.

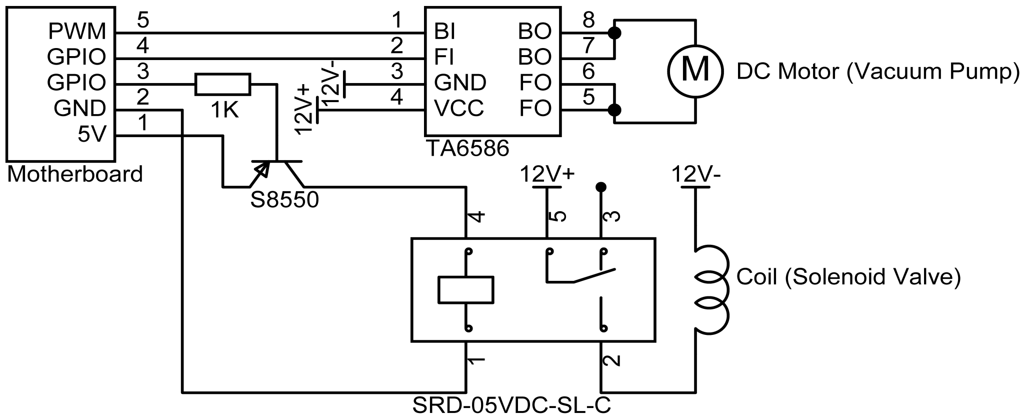

Figure 6. Pneumatic device control circuit connection diagram

3.2.4. Manipulator module

This project independently designs a manipulator module, including manipulator module bracket, vacuum nozzle, micro switch, spring, limit switch, camera module, laser-ranging module and negative pressure sensor and other devices. The manipulator module is shown in **Figure 7**.

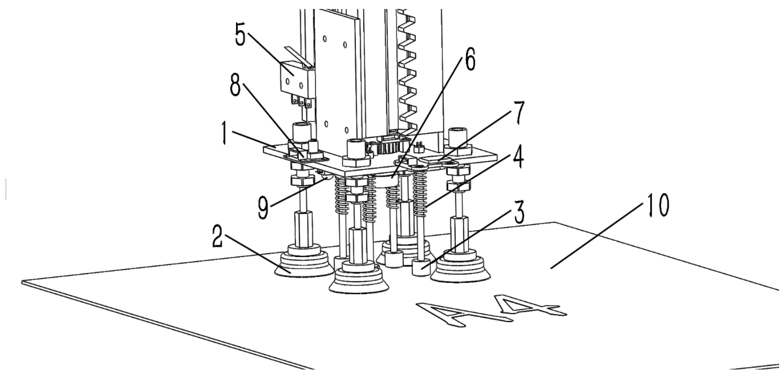

Figure 7. Schematic diagram of manipulator module. (1) Manipulator module bracket, (2)Vacuum nozzle, (3) Micro switch, (4)Spring, (5) Limit switch, (6) Camera module, (7) Laser-ranging module, (8) Negative pressure sensor, (9) Fill light, (10) Paper document

3.2.4.1. Camera module

This project uses HD USB free drive 120FPS, 2MP camera module. The camera module is installed in the manipulator and connected to the motherboard via USB, the camera is invoked by the program, combined with the You Only Look Once (YOLO) model to detect the position of the paper, combined with OCR to identify the text on the paper.

3.2.4.2. Negative pressure sensor module

This project uses the RSCM17100KN090 negative pressure sensor module. The negative pressure sensor module has a measurement range of -90 KPa to 0 KPa. The control pin of the module is connected to the motherboard, and the module will return the negative pressure value of the mini vacuum pump to the motherboard in real time. When the paper is absorbed or released abnormally, the system will automatically adjust the speed of the motor of the vacuum pump according to the negative pressure value. The principle of the negative pressure sensor module is shown in **Figure 8**.

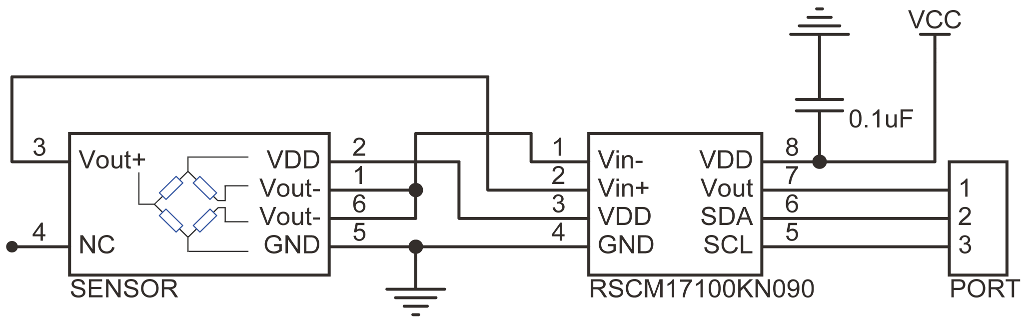

Figure 8. Schematic diagram of the negative pressure sensor module

3.2.4.3. Laser ranging module

The TOF050F laser ranging module is selected for this project. The laser ranging module is installed in the manipulator, and the control pin of this module is connected to the motherboard by the program to read the distance between the vacuum nozzle and the paper in real time.

3.2.4.4. Microswitch

The micro switch acts as a trigger sensor, which is installed in the manipulator and used to detect the contact or departure of the object to generate a high-low level signal input to the motherboard. As the manipulator descends and makes contact with the paper or the surface, a micro switch is activated, preventing the manipulator from moving any lower. The motherboard receives the signal indicating that the switch has been triggered, allowing it to halt the downward movement of the stepper motor.

4. Micro switch

The software design component of the project uses a Linux operating system as its base, with the programming implemented in Python language. The program is composed of hardware control system, artificial intelligence reasoning system, and human-computer interaction system. The hardware control system, and various external hardware, such as motor drive modules, relays, sensors, etc., are connected to the GPIO pins on the motherboard, and their operation is controlled by the program. The software includes an AI inference system that utilizes the YOLO deep learning object detection framework in Python. This system is connected to a camera, and configured to load a pre-trained YOLO model for paper position detection. It also incorporates Optical Character Recognition (OCR) models for text recognition on the paper, as well as Natural Language

Processing (NLP) models for processing natural language, including tasks like sentiment analysis, text classification, and text summarization. Additionally, there is a human-computer interaction system that employs HTML5, CSS, and JavaScript to create the web front-end. The Flask framework is used to construct the web-based human-computer interaction interface, which users can access via the IP address of the main control board within the same LAN [10]. The workflow of the software part is shown in **Figure 9**.

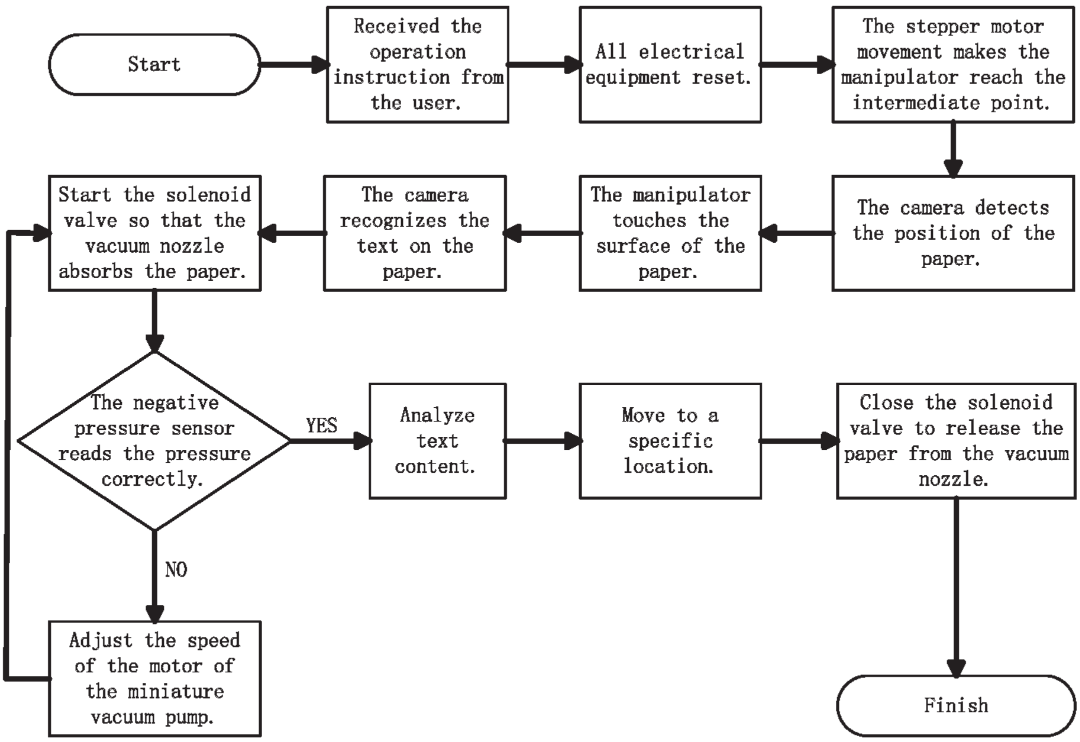

Figure 9. Flow chart of software

5. Conclusion

The paper document sorting robot developed in this project boasts a high level of automation, enabling efficient and precise sorting and classification of paper documents. It reduces the need for manual intervention and can even operate unattended, resulting in a significant improvement in document processing efficiency. This robot can rapidly process large volumes of documents while drastically reducing classification errors. It features a straightforward user interface, making it easy to operate, and is suitable for diverse scenarios, including libraries, archive rooms, and office environments. Furthermore, the project is highly scalable for future development, allowing for the addition of related devices and the creation of more practical functions. It can also be customized and expanded to cater to specific user requirements.

Disclosure statement

The authors declare no conflict of interest.

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Electron-Beam Welding Joint Strength of Dissimilar Materials

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Abstract: This paper provides an in-depth discussion of the joint strength of electron beam welding of dissimilar materials. The effect of welding parameters and material properties on the joint strength was analyzed, and an argument for the optimal parameter combination is presented. Electron-beam welding technology offers several advantages, including high energy density and the ability to create fine weld seams. However, it also presents certain challenges, such as the complexity of welding parameters and the potential generation of brittle phases. The analysis conducted in this paper holds significant importance in enhancing the quality and efficiency of dissimilar material welding processes.

Keywords: Electron-beam welding; Dissimilar materials; Joint strength

Online publication: November 29, 2023

1. Introduction

The study of the strength of electron-beam welding in joining dissimilar materials is of great significance in modern manufacturing and engineering fields. Electron-beam welding technology is precise and has high energy, making it a potentially effective method of joining dissimilar materials. The objective of this paper is to explore the application prospects of electron beam welding in joining dissimilar materials, with emphasis on the effect of welding parameters on joint strength. Differences between the chemical properties, crystal structures, and melting points of different materials often pose a challenge for welding dissimilar materials. The paper will cover a wide range of dissimilar material systems such as titanium alloys, steels, cemented carbides, and amorphous metallic glasses [1]. The optimum combination of welding parameters will be explored through experiments, and the microstructure and chemical composition of the welded joint region will be analyzed. The analysis in this paper aims to provide a deeper understanding of electron-beam welding of dissimilar materials and provide relevant references for engineering applications.

2. Electron-beam welding of dissimilar materials

2.1. Definition

Electron beam welding of dissimilar materials is a highly sophisticated welding technique that joins two or more different types of materials together by using an electron beam as a heat source [2]. This welding method relies on the energy of a high-speed electron beam that is capable of releasing extremely high heat on the weld area, causing the materials to melt rapidly and form a strong connection upon cooling. Unlike conventional welding methods, electron beam welding of dissimilar materials typically requires no external filler and completely relies on the molten material itself. Connections are formed when the materials solidify. This welding method is widely used in industry and scientific research, especially in the field of joining complex and dissimilar materials because of its high precision, quality, and efficiency [3].

2.2. Advantages

Electron-beam welding of dissimilar materials offers a multitude of advantages, which makes it popular in the field of material joining. Firstly, it forms strong joints. Electron beam welding can produce high-quality and strong welded joints. Due to its high energy density and precise focus control, the weld usually has a uniform organizational structure and is less susceptible to porosity, cracks, and other defects. Its excellent mechanical properties make it suitable for applications requiring high-strength joints. Secondly, electron-beam welding can join dissimilar materials. Electron-beam welding can achieve a reliable connection whether it is between metal and ceramics, metal and amorphous materials, or even different types of metals. This multi-material compatibility makes it favorable in many fields, such as aerospace and medical equipment and electronic equipment manufacturing. Furthermore, electron-beam welding allows for precise control of weld quality. Operators can accurately manage the focus position, welding speed, and electron beam power to maintain consistency throughout the welding process, resulting in high-quality welded joints. Additionally, E-beam welding typically results in a minimal heat-affected zone [4]. Due to its precise focal point control, electron-beam welding typically produces a small heat-affected zone, which is important for cases where the material properties are sensitive; it reduces the thermal stresses on the material during the welding process and helps retain the original properties of the material. Lastly, no filler material is required for electron-beam welding. Electron-beam welding eliminates the need for additional filler material because the welded material is completely melted during the welding process. This reduces production costs and eliminates the risk of introducing inhomogeneous filler material.

2.3. Challenges

Despite the numerous advantages of electron beam welding of dissimilar materials, it also poses several challenges. Firstly, it may cause the formation of intermetallic compounds. Brittle intermetallic compounds tend to form in some dissimilar metal welds, especially in metal-to-intermetallic compound welds. These relatively brittle regions may lead to brittleness of the welded joint and reduce its overall performance. Secondly, it may result in thermal and residual stresses. During the electron beam welding process, the high-temperature regions generated can lead to thermal and residual stresses in the welded joints. This can lead to deformation, cracking, or shape instability in the welded area, affecting joint performance and stability. Thirdly, welding equipment is costly. E-beam welding equipment is often expensive and complex, which limits its widespread use in certain applications. Maintaining, operating, and managing this equipment requires specialized knowledge and therefore higher costs. Electron-beam welding typically requires a longer preparation time compared to conventional welding methods. Fourthly, inhomogeneity between different materials can lead to inconsistencies in the quality of the welded joints. For example, differences in chemical composition and grain structure of materials can lead to uneven organization in welded joints. The last disadvantage of electron-beam welding is its environmental constraints. Electron-beam welding needs to be carried out in a vacuum or an inert atmosphere, which limits the flexibility of the welding activity and increases the complexity of the equipment [5].

3. Research design

In order to investigate the strength of the electron beam welded joints of dissimilar materials, a series of systematic studies was designed, specifically including the following key elements.

3.1. Material selection and pretreatment

Material selection and pretreatment are key steps in the study of the joint strength of electron beam welding of dissimilar materials that can affect the quality and joint strength of the welded materials [6]. Firstly, the welding materials need to be carefully selected. This involves considering the physical and chemical properties of the materials as well as the application scenario. It is important to ensure that the materials selected have relatively good metallurgical compatibility to minimize the problems that may arise during welding. Pretreatment of the material is also a must, including the removal of surface oxides, grease, and other contaminants to ensure the cleanliness of the material surface during the welding process. In some cases, special treatment of the material, such as heat treatment or mechanical treatment, is also required to improve the welding properties of the material. The selected materials should be subjected to appropriate dimensional processing to ensure the quality of preparation of the welded joints, including determining the geometry and dimensions of the joints to meet the requirements of the study [7].

3.2. Control of experimental parameters

The control of experimental parameters is crucial in the study of dissimilar materials' electron beam welding joint strength. These parameters directly affect the stability of the welding process and the quality of the welded joint [8]. The following are some important experimental parameters that need to be carefully and well controlled and adjusted. The key to electron beam welding is to precisely control the power and focus of the electron beam. Too much power can lead to excessive melting and weld deformation, while too little power can lead to incomplete melting of the weld. The control of focusing can affect the width and depth of the weld, which needs to be adjusted according to the material and welding requirements. Secondly, the scanning speed of the electron beam directly affects the distribution of heat input during the welding process. A scanning speed that is too high will lead to inadequate melting of the weld, while a low scanning speed will cause excessive heating. Therefore, it is necessary to select the appropriate scanning speed according to the welding material and requirements. Thirdly, the atmosphere during welding is also critical to the quality of the welded joint. Electron beam welding needs to be carried out in a vacuum or inert atmosphere to prevent oxidation and contamination of impurities. The atmosphere control needs to be kept stable to ensure the reliability of welding [9].

3.3. Joint preparation and processing

The preparation and processing of joints is an important part of ensuring the quality of welding, and the following are some key factors to be considered. The first factor is surface treatment. Before welding, the surface of the joint needs to be carefully treated, including the removal of any dirt, oxides, and impurities to ensure the purity of the welded area. Chemical cleaning, mechanical polishing, or other methods are often used to achieve surface preparation. Secondly, the geometry of the joint is critical to the quality of the weld. It is important to ensure that the size and shape of the joint meet the design requirements to achieve a uniform weld and a strong joint. The third factor is the joint assembly. Before placing dissimilar materials in the electron beam welding equipment, it is important to ensure that they are properly assembled, including ensuring that the materials are aligned and clamped to prevent shifting or distortion during the welding process. The fourth factor is the preheating process. For some dissimilar material combinations, preheating is necessary to minimize thermal stresses and the heat-affected zone of the material during welding, and the preheating temperature and time need to be determined based on the nature of the material [10].

3.4. Strength test methods

A strength test is a key step to evaluate the performance of welded joints, the following strength test methods are commonly used. Firstly, the tensile strength test is the most common in evaluating the strength of the welded joints. In this test, the welded joint is loaded and the tensile force is gradually applied when it ruptures. The testing machine records the stress-strain curve to determine the maximum tensile strength and the plastic deformation of the material. Second, hardness testing evaluates the strength of a welded joint by applying a load to it and measuring the hardness of the material, which can be accomplished using a differential hardness tester or a Brinell hardness tester. Thirdly, impact testing is used to evaluate the toughness of welded joints. In this test, an impact load is applied to the joint to simulate the impact loads in real life to determine whether the joint can withstand sudden impacts. Fourthly a metallographic analysis provides information on the microstructure of the weld area, which is useful in determining the quality of the weld, as well as looking for possible defects and problems. This method involves cutting, grinding, etching, and microscopic observation of the sample [11].

4. Result analysis and discussion

4.1. Welding parameter analysis

In this paper, the following two grades of electron-beam welding materials were selected: Material A and Material B. Material A material was a high-strength stainless steel alloy, 316 stainless steel. This stainless steel is widely used in many industries and is known for its corrosion resistance and mechanical strength. This material can be chosen to simulate common application scenarios in real industry, such as pipe joining, tank fabrication, etc. Material B was a high-strength alloy, Ti-6Al-4V titanium alloy. Titanium alloys have an excellent strength-to-weight ratio, and are therefore widely used in areas such as aerospace and medical device manufacturing. These materials enable the study of the performance of electron beam welding on high-strength alloy materials [12].

By using these two different grades of materials in experiments, it is possible to simulate situations that may be encountered in real engineering, such as the fabrication of joints made of different materials, which may be used in aerospace, petrochemical, or medical device fields. Such studies help to understand the characteristics of electron beam welding between dissimilar materials and how to optimize the welding parameters to obtain high strength and quality joints [13].

When electron beam welding dissimilar materials, different welding parameters can significantly affect the joint properties, and the experimental results for each parameter were analyzed. Firstly, a series of experiments were conducted to adjust the power of the electron beam. When the electron beam power was 3000 watts, the welding speed was faster, but the weld depth was limited, and the joint strength was 450 MPa. When the power was increased to 6000 watts, the welding speed slowed down, and the weld depth increased, but the weld area started to overheat, which led to a decrease in the strength of the joint to 380 MPa. Finally, when the power of the electron beam was adjusted to 4500 watts, a good balance between the welding speed and depth was achieved, and the strength of the joint reached 380 MPa.

The experimental results indicate that when choosing the electron beam power, there is a need to strike a balance between welding speed and the quality of the weld seam. Excessively high or low power levels can have an impact on the joint performance [14].

Secondly, the focusing of the electron beam was adjusted. The experimentation showed that with a strong focus, resulting in a sharp focus and high energy density in the welding area, the weld depth increased, but it led to welding instability with a joint strength of 490 MPa. Conversely, with a weak focus and larger focus area, the welding speed increased, but the weld depth decreased, resulting in a joint strength of 480 MPa. The optimal choice was a moderate focus, where both weld depth and welding speed were within acceptable ranges, resulting in a joint strength of 500 MPa.

Thirdly, the scanning speed was adjusted. A higher scanning speed (10 mm/s) resulted in a shallower weld with a joint strength of 480 MPa, while a lower scanning speed (5 mm/s) increased the weld depth but reduced the welding efficiency with a joint strength of 490 MPa. In this paper, the moderate scanning speed (7.5 mm/s) was finally chosen to balance the weld depth and the efficiency, and the joint strength reached 500 MPa.

Fourthly the experiments were carried out in a vacuum environment to prevent oxidation during welding and to ensure the quality and purity of the weld. Through the aforementioned experiments, the optimal combination of welding parameters to obtain high-strength electron beam welded joints of dissimilar materials was determined.

4.2. Material characterization

In electron beam welding of dissimilar materials, the characteristics of the materials have a significant effect on the performance of the joint. **Table 1** shows the experimental data of two different materials and their characteristics.

Table 1. Experimental data of two different materials and their characteristics

Properties	Material A (titanium alloy)	Material B (aluminum alloy)
Tensile strength	> 600MPa	Approx. 300MPa
Melting point	Approx. 1668°C	Approx. 660°C
Thermal conductivity	Lower	Higher

Based on **Table 1**, it is clear that there are significant differences between Material A and Material B in terms of tensile strength, melting point, and thermal conductivity, and these differences affect the process and results of electron-beam welding.

Firstly, Material A has a higher tensile strength, therefore requiring higher welding power to ensure that enough heat is transferred to the weld area to achieve a good fusion. On the contrary, Material B requires lower power to avoid overheating.

In terms of melting point, the high melting point of Material A requires a longer welding time to ensure sufficient heat input, while the low melting point of Material B requires a higher welding speed to prevent overheating.

Thirdly, in terms of thermal conductivity, the high thermal conductivity of Material B causes it to dissipate heat more quickly during the welding process, requiring higher welding power to compensate for the heat loss.

Considering the diverse material properties involved, it becomes essential to make tradeoffs when selecting welding parameters for achieving high-quality electron beam welded joints in dissimilar materials. The variations in material characteristics necessitate designers to make adjustments on a case-by-case basis, aiming for optimal welding results.

5. Conclusion

This study focused on researching the joint strength of dissimilar materials using electron beam welding, to thoroughly explore the application prospects of electron beam welding technology under different material combinations. By analyzing the definition, characteristics, advantages, and challenges of electron beam welding, a theoretical basis for the research design can be provided. In terms of research design, this paper focuses on key steps such as material selection and material pretreatment, experimental parameter control, joint preparation and processing, and strength test methods, which were reasonably designed to ensure the accuracy and reliability of the experiment. Besides, the influence of welding parameters and material properties on joint strength was also investigated. Through the detailed analysis of these factors, a series of conclusions can be drawn, which provide strong support for the determination of the optimal parameter combinations [15]. In conclusion, this study provides a comprehensive analysis of the joint strength of dissimilar materials through electron beam welding, offering a useful reference for practices in related fields. It is anticipated that the potential of this field can be further explored in the future to promote the continuous progress of related technologies.

Disclosure statement

The authors declare no conflict of interest.

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The Application of Electron-Beam Welding in Pellet Mold Preparation

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Abstract: This paper provides insight into the application of electron-beam welding in pellet mold preparation, highlighting the importance of the combination of electron-beam welding and pellet mold preparation in the fields of microstructure joining and micro- and nanostructure preparation. Precise material joining and microstructure fabrication can be achieved by the precise control of electron-beam welding and the shape adjustment of pellet molds. These applications hold significant potential in the modern industrial field, providing robust support for the development of new materials and the growth of the petrochemical industry. This paper asserts that in the future, the ongoing development of electron-beam welding and pelletizing template technology will unlock new possibilities in the field of petrochemicals, fostering progress in science and technology.

Keywords: Electron-beam welding; Pellet mold; Microstructure

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1. Introduction

Electron-beam welding plays a key role in the development of the petrochemical industry. This technology has unique advantages, such as high focal energy density, precise welding control, and low heat input, making it popular in several fields. Pellet molds are also a key technology in the petrochemical industry that helps to improve the efficiency of petroleum product manufacture and has a broad application prospect. Exploring the potential applications of combining electron-beam welding with pellet mold preparation in the petrochemical field poses several challenges [1]. The objective of this paper is to study the application of electron-beam welding on pellet mold welding in order to determine its feasibility in the petrochemical industry. This study is expected to bring new development ideas to the petrochemical industry and promote the application of electron-beam welding technology in this field.

2. Electron-beam welding

2.1. Working principle of electron-beam welding

Electron-beam welding is a highly sophisticated welding technique that functions on the basis of a high-speed electron beam [2]. In this welding method, an electron gun is used to generate a stream of high-speed electrons that emit energy through a hot cathode. These high-speed electrons are guided by an electric field and condensed into a fine stream of beams containing a huge amount of energy, which is then shot at the welding spot. The high-energy electron beam is focused on the weld seam of the workpiece and is extremely penetrating. Technicians can precisely control the energy of the electron beam to ensure that the heat generated during the welding process is highly concentrated minimizing its impact on the surrounding material [3]. The energy of the electron beam is converted into heat at the welding point, resulting in instantaneous melting or fusion of the workpiece material. The principle of electron-beam welding has several features. Firstly, the electron beam has a very high energy density, which can generate high temperatures at the welding point, realizing rapid melting and fusion of materials. Secondly, because the focus of electron-beam welding is extremely precise, its heat input is very low, so it does not have a thermal impact on the surrounding material, reducing the probability of deformation and stress. Thirdly, by adjusting the energy of the electron beam, the welding depth can be precisely controlled to adapt to different types of materials. Lastly, electron-beam welding can be integrated with computerized control systems to further automate the welding process [4].

2.2. Electron-beam welding parameters

The quality of electron-beam welding is closely related to the control of welding parameters. In the electron-beam welding process, several parameters need to be carefully controlled to ensure the welding quality. The first parameter is the electron beam energy density. This is an important parameter in welding, and the energy density of the electron beam directly affects the depth of the weld. By adjusting the current of the electron beam, the energy density can be precisely controlled to adapt to the welding requirements of different materials [5]. The second parameter is the focal diameter. The focal diameter is the size of the focal point of the electron beam. By adjusting the focal diameter, the width of the weld can be controlled. Smaller focal diameters are usually used for fine welds, while larger focal diameters are used for wider weld areas. The fourth parameter is the welding speed. The welding speed is the speed at which the electron beam moves during the welding process. It is closely related to energy density and weld depth. High welding speeds reduce heat input and are suitable in certain situations, while lower speeds will be needed to create deeper welds [6]. Lastly, the environment plays an important role in electron-beam welding. Inert gases, such as argon, are used to protect the weld area from oxidation and impurities. The parameters of electron-beam welding are shown in **Table 1**.

Table 1. Parameters of electron-beam welding

<table>
<tr><th rowspan="2">Type of joint</th><th rowspan="2">Welding position</th><th rowspan="2">Plate thickness，(mm)</th><th colspan="2">First layer of the weld channel</th><th colspan="2">Welding passes for the remaining layers</th></tr>
<tr><th>Diameter of welding rod (mm)</th><th>Welding current (A)</th><th>Diameter of welding electrode (mm)</th><th>Welding current (A)</th></tr>
<tr><td>Straight edge buttressing</td><td>Flat welding</td><td>4–5</td><td>3.2</td><td>90–120</td><td rowspan="2">4</td><td rowspan="2">160–180</td></tr>
<tr><td rowspan="3">Single-sided V-butt</td><td rowspan="3">Flat welding</td><td rowspan="3">> 6</td><td>4</td><td>160–180</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">160–180</td><td>4</td><td>160–180</td></tr>
<tr><td>5</td><td>200–240</td></tr>
<tr><td rowspan="2">X-butt</td><td rowspan="2">Flat welding</td><td rowspan="2">> 12</td><td rowspan="2">4</td><td rowspan="2">160–180</td><td>4</td><td>160–180</td></tr>
<tr><td>5</td><td>200–260</td></tr>
</table>

3. Introduction to pellet molds

3.1. Definition of pellet mold

A pellet mold is a tool used to prepare granular materials. It is a template with specific shaped holes or grooves that determine the shape and size of the granular material. These holes or grooves can be spherical, cylindrical, conical, etc., depending on the desired shape of the granules [7]. Pellet molds are widely used for the preparation of granular materials in petrochemical processes. These molds have a key role in refining, chemical production, and petroleum processing. The main function of pellet molds is to convert powdered or granular raw materials into uniform granular materials. This is important for a variety of processes in the petrochemical industry, such as the production of granular catalysts, granulation of powdered additives, and coating of granular materials [8]. Through granulation, the flow, storage, and transportation of raw materials can be improved, along with the homogeneity and stability of the product. Secondly, pellet molds usually include a template aperture plate. These plates are used to control the size and shape of the pellets. The selection and design of the template apertures are critical in the pelletizing process because they directly affect the physical properties of the final product. Finally, the preparation of pellet molds usually involves complex processes that include steps such as mixing raw materials, pelletizing, drying, and cooling. These processes require precise control parameters such as temperature, humidity, flow rate, etc. to ensure the quality of the final product. In the petrochemical industry, the wide range of applications of granular products requires continuous improvement and optimization of the pellet mold manufacturing process to meet different process requirements and product specifications [9].

3.2. Pellet mold preparation methods

Pellet molds can be prepared by various methods depending on the shape and material properties of the desired product. The first method is photolithography. This is a common micro- and nano-fabrication method for preparing molds with tiny holes or patterns. In this method, a photosensitive material is coated on a substrate, and then a mask and UV light irradiation are used to chemically react the photosensitive material to form the desired pattern. The unwanted parts are removed by chemical etching or corrosion, leaving the template. The second method is the electron beam etching method. This method is similar to photolithography but an electron beam is used to expose the photosensitive material. This method allows for the preparation of smaller-sized holes, as well as more complex mold patterns. The next method is the electrochemical etching method. In this method, the substrate is immersed in an electrolyte, and holes or grooves are formed in the substrate through an electrochemical reaction, in which the size and shape of the holes can be controlled precisely. The last method is the mold method. Pellet molds are prepared using molds that have the desired shape of the holes or grooves. The material is heated and injected into the molds, then cooled and hardened, resulting in the desired template. Each preparation method has its unique advantages, which can be utilized for different purposes. In the pharmaceutical industry, choosing the right method of preparing pellet molds is crucial to ensuring the consistency of drug particles [10].

3.3. The role of pellet molds in the petrochemical industry

Pellet molds play an important role in the petrochemical industry, especially in the preparation of catalysts [11]. Catalysts play a central role in petroleum refining and chemical production. By using pellet molds, the catalyst feedstock can be converted into homogeneous particles, which ensures uniform distribution during the reaction and thus improves the reaction efficiency. This step is essential for petrochemical processes such as cracking, hydrogenation, and catalytic reforming. Secondly, pellet molds also play an important role in the application of additives. In the petrochemical industry, additives such as antioxidants, adsorbents, etc. are usually required in a powdered or liquid form. Through granulation, these additives can be more easily mixed with the substrate, improving handling and homogeneity while reducing dust generation, which is critical for ensuring both process stability and product quality. Finally, pellet molds also help to improve the handling of powders. In the petrochemical industry, it is often necessary to handle powdered feedstocks, such as drying, cooling, and sieving of pellets. The application of pellet molds improves the flow and handling properties of powders, which increases productivity and reduces possible problems in production [12].

4. Combination of electron-beam welding in pellet mold welding

When electron beam welding is applied in fusion with pellet molding technology, they present excellent potential in the field of joining microstructures [13]. This combination provides new opportunities to realize precise connections, especially for microstructures.

4.1. Precise joining of microstructures

In the petrochemical industry, the combination of electron-beam welding in pellet mold preparation plays a key role, especially in the precise joining of microstructures. This combination allows fine work and enables highly precise and controllable joining at a microscopic scale. First, this combination provides an important tool for the petrochemical field in the preparation of microstructures. For example, precise connections of microstructures are needed in the fabrication of microreactors or microsensors to ensure their efficient operation in petrochemical applications. The synergistic application of electron-beam welding in pellet mold manufacture helps to prepare fine micro-components needed in petrochemical processes. Secondly, this combination can potentially be used for device preparation in the field of nanotechnology. Nanoscale devices are required in the petrochemical industry for precise monitoring and control. The integration of electron-beam welding in pellet mold production helps in the preparation of high-precision nanosensors, nanocatalysts, etc., to support microscopic operations in petrochemical processes. Furthermore, this combined technology offers flexibility in customizing microstructure connections. This is important to meet the specific needs of different petrochemical processes, such as customized interconnections for microsensor networks. Finally, this technology also plays a role in the encapsulation of tiny structures. In the petrochemical sector, some microstructures need to operate in harsh environments and therefore require effective encapsulation to protect them from the external environment. The integration of electron-beam welding in pellet mold production provides a reliable encapsulation method to ensure the reliable operation of microstructures in unfavorable industrial environments [14].

4.2. Micro- and nanostructure preparation

In the petrochemical field, the integration of electron-beam welding in pellet mold production provides a precise and controlled method for the preparation of micro- and nanostructures [15]. This technology combination can be applied to the preparation of microscale and nanoscale devices. By combining electron-beam welding and pellet mold technology, microparticles and nanostructures can be effectively connected and assembled to prepare microscale and nanoscale devices, such as microreactors, nanosensors, and nano-optical elements. These devices have a wide range of applications in the petrochemical field, such as catalytic reactions, fine analysis, and chemical sensing. Second, this combination of techniques can be used to precisely control the preparation of nanopores. Electron-beam welding can be utilized to join and close templates with nanoscale pores, which is useful in preparing micro and nanostructures with specific pore sizes and shapes, such as nanofilters, nanoreactors, and separators. These structures are used in the petrochemical industry for controlling the transfer and separation of substances. Besides, this combination of technologies can support the synthesis of nanoparticles. The synthesis of nanoparticles can be achieved through the combined use of electron-beam welding and pellet mold technologies to prepare nanoparticles with specific shapes and properties. These nanoparticles can be used in petrochemical applications such as drug delivery, catalytic reactions, and material modification. Finally, this combination of technologies helps to achieve precise joining of micro and nanostructures. Through the integration of electron-beam welding in pellet mold production, it is possible to ensure the precise assembly of micro and nanostructured substances. This is critical for applications in petrochemicals that require precise control of structure and properties, such as integrated circuit preparation and production of nanomaterials in microelectronics [16].

4.3. Precise joining of micro- and nanostructures

Precision is crucial in the field of preparing and joining structures at the micro- and nanoscale. The preparation of micro- and nanostructures requires confining chemical reactions and structural connections to the tiny scale to ensure a high degree of precision and control. This task involves using electron-beam welding technology, enabling targeted heating and fusion of metals or insulators at the nanoscale to create tiny reaction cavities or channels. Pellet molds also play a key role in controlling the size and shape of the reaction cavities to ensure that they conform exactly to the design specifications. Secondly, the preparation of micro- and nanostructures requires ensuring that catalysts or reactants are precisely dispersed in tiny spaces. The application of electron-beam welding allows precise positioning of the catalyst or reactants, while the pellet mold ensures uniform distribution. This highly precise catalyst positioning and dispersion is essential for improving reaction efficiency and selectivity. Moreover, the structure must be hermetically sealed and stable in the preparation of micro- and nanostructures to avoid reactant leakage or external interference. Electron-beam welding can be used to join and seal the components of the micro- and nanostructures to ensure superior hermeticity, especially in high-pressure, high-temperature, or chemically aggressive environments. Finally, the precise fusion of micro- and nanostructures requires corresponding testing and validation steps to ensure that the structure performs as expected, including a thorough evaluation of key parameters such as reaction rate, selectivity, and product distribution. With the synergistic application of electron-beam welding in pellet mold production, precise control and a high degree of reproducibility can be achieved, thus facilitating accurate performance testing.

5. Conclusion

The application of electron-beam welding in pellet mold production and the combination of the two in the areas of microstructure joining, drug delivery system preparation, micro- and nanostructure preparation, and biomedical device manufacturing were explored in this paper. The integration of electron-beam welding in pellet mold production allows precise drug carrier preparation, customized device manufacturing, precise joining of micron- and nanoscale structures, and high-quality manufacturing of biomedical devices. The emergence of these applications not only enriches research in related fields, but also brings great opportunities for pharmaceutical manufacturing. These technologies will continue to evolve in the future, offering the possibility of solving even more complex problems.

Disclosure statement

The authors declare no conflict of interest.

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Countermeasures to Strengthen Teaching Facilities in the Information Age

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Abstract: Teaching security management is important for institutions to effectively manage teaching resources. This article takes Xi'an Mingde Institute of Technology (referred to as Mingde Institute) as the research subject and uses the literature review and field investigation to put forward relevant suggestions for the teaching facilities of Mingde Institute, in order to improve the teaching facilities of Mingde Institute.

Keywords: Informatization; Teaching facilities; Management measures

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1. Introduction

The quality of teaching facilities affects the construction level and core competitiveness of higher education institutions to a great extent. In the current transformation period of major private universities, many new problems have emerged in the acquisition and processing of teaching support information and the allocation and adjustment of teaching resources. The current material and funds can no longer meet the needs of college teaching, and technical support will become the main content of support works. Some scholars have studied teaching facilities from the aspect of multimedia teaching, briefly introduced the shortcomings in multimedia classroom management in colleges and universities, and put forward suggestions for strengthening multimedia classroom management [1]. Some scholars briefly elaborated on the importance of the digital construction of college education and the application of digital platforms and analyzed the existing problems in the construction of college teaching informatization. Several targeted countermeasures and suggestions have been put forward to further develop and promote teaching management informatization [2], create a good atmosphere, and improve relevant systems. Some scholars have conducted research on the management of computer rooms in universities and found some problems like software and hardware protection issues, power safety issues, etc., and have put forward relevant suggestions [3]. Therefore, it is important to utilize modern computer technology and network technology in teaching facilities to further promote the healthy development of teaching facilities in various universities.

2. Existing problems in teaching facilities

2.1. Multimedia classroom issues

2.1.1. Lack of complete rules and regulations

Due to the lack of standardized systems and processes and unclear management responsibilities, equipment maintenance is not timely and faults cannot be solved quickly [4]. In addition, due to the lack of a reward and punishment system, some poor behaviors cannot be effectively eradicated, resulting in undesirable outcomes.

2.1.2. Outdated classroom equipment

Due to aging, key equipment such as projectors and computers often malfunction, affecting teaching work. In order to ensure the quality of teaching, the equipment needs to be updated regularly to ensure their reliability.

2.1.3. Insufficient provision of professional and technical personnel

The equipment of the multimedia classroom requires the support of professional and technical personnel. However, due to the shortage of technical personnel, there is often a situation of "demand exceeding the supply." Therefore, increasing the number of professional and technical personnel and improving their skill levels is the key to solving this problem.

2.1.4. Traditional multimedia teaching equipment maintenance methods

At present, equipment maintenance mostly relies on traditional means and methods, lacking modern and intelligent maintenance methods. This not only increases maintenance costs, but also reduces maintenance efficiency [5]. Therefore, it is necessary to introduce advanced maintenance methods and technologies to improve the level of equipment maintenance.

2.1.5. Lack of proficiency in using multimedia equipment

Some teachers lack the skills to operate multimedia equipment. This not only affects the teaching effect, but may also cause damage to the equipment. Therefore, teachers need to be trained and guided to improve their proficiency in using multimedia equipment to ensure the quality of teaching.

2.2. Teaching support issues in computer rooms and speech laboratories

2.2.1. Flawed management systems

The management system of computer rooms and speech laboratories is imperfect. This is mainly reflected in the lack of clear rules and regulations, unclear management responsibilities, and lack of effective monitoring mechanisms. These problems may lead to untimely equipment maintenance and equipment failures that cannot be quickly resolved, thus affecting the teaching quality.

2.2.2. Lack of awareness of electrical safety among students

Students' lack of awareness of electrical safety in computer rooms and speech laboratories is also a common problem. Due to the lack of awareness and knowledge of electricity usage, students may operate power cords illegally and connect power sockets without permission, which may easily lead to accidents.

2.2.3. Outdated teaching equipment in computer rooms and speech laboratories

In higher education institutions, due to insufficient capital investment or other reasons, the teaching equipment in computer rooms and speech laboratories may be outdated. These devices may have problems such as low performance and frequent failures, which affect the teaching effects. In addition, the update and maintenance of equipment is also an issue that needs to be addressed.

2.2.4. Teachers being unfamiliar with the equipment in the computer room and speech laboratory

Due to the lack of relevant training and guidance, teachers may not be familiar with the equipment in the computer rooms and speech laboratories. As a result, the equipment cannot be fully utilized to achieve the best teaching effect.

2.3. Problems in the informatization of teaching

2.3.1. Insufficient understanding of informatization

The lack of understanding of information-based teaching is the core problem in the management of information-based teaching. This is mainly reflected in the insufficient understanding of the importance, necessity, and urgency of informatization, and the lack of understanding of the basic concepts, characteristics, laws, and models of information-based teaching. Due to the lack of understanding, some educators fail to maximize the benefits of information-based teaching in improving teaching quality and promoting educational equity.

2.3.2. Lack of information-based teaching design and resource integration capabilities

The design and resource integration capabilities of informatized teaching are the key to promoting informatized teaching. However, these two aspects are yet to be optimized. Specifically, some educators are unable to effectively use information technology to design courses and cannot integrate various information-based teaching resources according to different teaching contents and goals to design an information-based teaching model suitable for students.

2.3.3. Lack of information-based evaluation and feedback mechanism

The effect of teaching informatization needs to be reflected through scientific evaluation and feedback mechanisms. However, there is a lack of scientific evaluation and feedback mechanisms. On one hand, it is impossible to accurately evaluate learning effects and teaching effects; on the other hand, it is impossible to collect feedback on students' learning situations and problems promptly, and it is also impossible to adjust and improve information-based teaching models and methods promptly.

2.3.4. Insufficient management training and technical support

Management training and technical support are important aspects of promoting informatized teaching. However, in the process of promoting teaching informatization, higher education institutions lack professional information technology talents and management talents, and are therefore unable to provide teachers with sufficient technical support and training.

3. Methods for improving the use of multimedia classrooms

3.1. Establishing and improving people-oriented rules and regulations

The rules and regulations regarding the use, management, and maintenance of multimedia classrooms should be improved, the management responsibilities should be well-defined, and the normal operation of multimedia classrooms and the safety and stability of equipment should be ensured [6]. At the same time, an incentive and evaluation mechanism should be established to encourage teachers to actively use multimedia teaching equipment to improve teaching quality and effectiveness.

3.2. Timely update of obsolete teaching equipment

Old or malfunctioning equipment should be updated or repaired in a timely manner [7]. When updating equipment, its performance, compatibility, and ease of use should be taken into consideration to improve the reliability and stability of the equipment and ensure the highest teaching quality.

3.3. Strengthening the construction of professional teams

The construction of professional teams in multimedia classrooms and the skills of professional and technical personnel should be strengthened. Through regular training and experience exchange, they can master advanced maintenance and management technologies and improve their ability to solve faults [8]. At the same time, the assessment and evaluation mechanism for professional and technical personnel should be improved to encourage them to better serve multimedia teaching.

3.4. Building an innovative multimedia teaching equipment maintenance model

The multimedia teaching equipment maintenance model should be renewed, with the introduction of modern and intelligent maintenance methods and technologies, so as to improve maintenance efficiency and quality. For example, using remote monitoring and online maintenance to detect and solve equipment faults in a timely manner [9] or establishing an equipment fault database to accelerate troubleshooting.

3.5. Strengthening information technology training for classroom teachers

Information technology training should be carried out for classroom teachers to improve their operating skills and maintenance awareness of multimedia equipment. The training content should include the basic principles of equipment, operating methods, common faults, and troubleshooting, etc. At the same time, the teachers will also need to be trained to apply the equipment in their lessons to achieve the best teaching results.

4. Teaching facilities: Computer rooms and speech laboratories

4.1. Strict computer room and speech laboratory management system

(1) Laboratory managers: Laboratory managers should comprehensively manage and maintain the computer rooms and voice laboratories to ensure the normal operation of the equipment and prevent vandalism and theft.

(2) Students: Before entering the computer room and speech laboratory, students must read the relevant rules and regulations of the computer room and speech laboratory, and operate in accordance with the prescribed operating procedures. Besides, they should not be allowed to carry USB flash drives, mobile hard disks, and other mobile storage devices without permission. When entering computer rooms and speech laboratories, it is prohibited to copy, delete, or modify files and data in the devices without permission [10].

(3) Teachers: Teachers should have good professional qualities, abide by the institution's regulations and equipment operation procedures, not dismantle or repair equipment in the computer room and speech laboratory without permission, and not take items that belong to the computer room and speech laboratory outside [11]. If students are found to be operating in violation of regulations during class, they should be stopped immediately and dealt with seriously.

4.2. Upgrading outdated teaching equipment regularly to improve teaching efficiency

The equipment in the computer room and speech laboratory should be upgraded regularly according to the institution's needs to improve teaching efficiency.

4.3. Posting up regulations and rules of electricity safety system for the user's attention

(1) Electrical safety regulations should be formulated and pasted in a prominent position. This system should include electricity safety instructions, and first aid measures for electric shocks, so as to remind the people entering the computer room and speech laboratory to pay attention to electricity safety [12].

(2) Computer room and speech laboratory managers should regularly perform inspections to ensure that the wires and electrical equipment comply with national safety standards.

(3) Computer room and voice laboratory managers should provide students with necessary anti-shock equipment, such as power strips, etc.

4.4. Strengthening information technology training for classroom teachers

Class teachers are the key to ensuring teaching quality, and the same is true for the teaching facilities like computer rooms and speech laboratories. Therefore, higher education institutions should strengthen information technology training for classroom teachers and improve teachers' proficiency and troubleshooting capabilities in using related equipment, so that teachers can better utilize the equipment.

5. Management measures for teaching information platform

5.1. Strengthen teaching concepts and create a good atmosphere

(1) The publicity and awareness of information-based teaching should be strengthened. This can be achieved by holding lectures, seminars, demonstration classes, and other activities. Through these activities, the necessity, concepts, and advantages of information-based teaching can be made clear to the teachers and students.

(2) A good information-based teaching environment should be created with sufficient software and hardware resources to meet the needs of teachers and students. The campus network construction should be strengthened to achieve full wireless network coverage in the teaching area and improve the convenience of information-based teaching [13].

(3) Teachers should be encouraged to carry out innovative information-based teaching practices and be provided with necessary support and guidance. Besides, information technology should be utilized to improve teaching methods and improve teaching effects and student learning effects [14].

5.2. Scientifically design management systems

(1) A proper teaching information management system plan should be formulated to clarify each work's responsibilities and procedures, and ensure that all works are carried out in an orderly manner.

(2) An information-based teaching resource library that integrates various high-quality teaching resources should be established. At the same time, the quality of teaching resources should also be monitored to ensure the accuracy and reliability of resources [15].

(3) An information-based teaching evaluation mechanism should be established to conduct comprehensive evaluations from aspects such as knowledge mastery, improvement, and learning attitude, so as to comprehensively reflect students' learning situations and teachers' teaching effects.

5.3. Increase system training and learning

(1) Information-based teaching training should be provided to managers, teachers, students, etc., to ensure

that personnel in different positions have sufficient knowledge of information-based teaching.

(2) New teachers should be provided with systematic information-based teaching training to help them quickly adapt to the information-based teaching environment and improve teaching quality and effectiveness.

(3) Teachers should be encouraged to participate in various information-based teaching competitions and evaluation activities. Competitions can be held to improve teaching and learning skills, and also promote the usage of information technology in teaching.

(4) Collaboration with league universities should be improved, so that our institution can learn from the experiences and practices of other advanced institutions and improve the informatization of teaching in our institution.

6. Summary

Strengthening teaching- facilities is an important means to improve teaching quality and realize educational modernization. By improving the teaching equipment, strengthening teacher training, optimizing teaching resources, and other measures, teaching and learning effects can be effectively improved. However, the strengthening of teaching facilities cannot be achieved overnight and requires continuous investment and improvement.

In the future, it is necessary to pay more attention to the application and innovation of information-based teaching, constantly optimize teaching equipment and resources through continuous exploration and practice, promote the organic integration of information-based teaching and traditional teaching, so as to improve the quality of education. At the same time, it is also necessary to actively address the challenges in information-based teaching, such as the digital gap, network security, and other issues. While ensuring the quality of teaching, the needs and abilities of students in different regions and at different levels should be considered to avoid unfairness caused by technological differences. In addition, the strengthening of teaching facilities require the joint efforts and support of the whole society. Governments, higher education institutions, enterprises, and other parties should work together to promote the development of information-based teaching and contribute to the modernization of education and the cultivation of high-quality talents.

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Research on the Cultural Construction of Private University Laboratories Based on Cultural Education

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Abstract: University laboratories serve as crucial hubs for scientific and technological innovation and play a vital role in nurturing talents. As pivotal spaces for both teaching and scientific research, the development of laboratories necessitates not only investment in scientific research equipment and experimental facilities but also in cultural construction. This cultural aspect holds significant importance in promoting the comprehensive development of students and enhancing scientific research capabilities. This article concentrates on the strategies for cultivating laboratory culture in private universities, addressing six key dimensions: spiritual culture, institutional culture, scientific culture, innovation culture, safety culture, and shared culture.

Keywords: Laboratory; Cultural education; Cultural construction; Private universities

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1. Introduction

University laboratories serve as pivotal hubs for scientific and technological innovation and play a crucial role in nurturing talents [1]. While substantial investments are made in laboratory hardware during construction, private university laboratories must also prioritize the development of the soft power inherent in laboratory culture. This article integrates spiritual culture, institutional culture, scientific culture, innovation culture, safety culture, and sharing culture.

The construction of laboratory culture holds immense significance, contributing to the reform and implementation of experimental teaching, the consolidation of subject concepts, the enhancement of the school's reputation and attractiveness, and the establishment of the school brand. In addition, fostering an excellent teaching and study style in the talent training process is essential for improving teaching quality. It plays an important role in cultivating students' rigorous scientific attitudes, and professional practical abilities, and stimulating exploratory and innovative thinking [2].

2. Theoretical basis for the construction of university laboratory culture

Laboratory culture constitutes a vital component of campus culture construction, representing a cultural form intricately linked to the laboratory itself. It plays a key role in the survival and development of the laboratory, serving as an enduring intangible asset within laboratory construction [3].

The construction of laboratory culture encompasses material culture, institutional culture, and spiritual culture. Material culture emphasizes the ambiance and professional characteristics of the laboratory, encompassing elements such as experimental buildings, equipment, and decor. Spiritual culture, an implicit facet of this culture, embodies the school‘s spirit, teaching style, study approach, class demeanor, and interpersonal relationships. This is manifested through professional development, historical evolution, participation in science and technology competitions, and engagement in teaching and research activities. Institutional culture, functioning as an internal guarantee mechanism, dictates the development and continuity of laboratory culture. It includes components such as the “Laboratory Safety and Health System,” “Experimental Instructor Work Responsibilities,” “Student Experiment Code,” “Experimental Teacher Job Responsibilities,” and “Experimental Teacher Class System.” The schematic representation of laboratory culture construction is illustrated in **Figure 1**.

- Laboratory culture
  - Material culture
    - Experimental building
    - Experimental instruments and equipment
    - Interior and exterior decoration
    - Introduction to instruments and equipment
    - Teaching results display
  - Spiritual culture
    - Professional construction
    - Development path
    - Technology competition
    - Teaching and research activities
  - Institutional culture
    - “Laboratory Safety and Health System”
    - “Experimental Instructor Job Responsibilities”
    - “Student Experiment Code”
    - “Experimental Teacher Job Responsibilities”
    - “Experimental Teacher Class Sitting System”

Figure 1. Construction content of laboratory culture

3. The educational function demonstrated by the cultural construction of university laboratories

In December 2016, General Secretary Xi Jinping emphasized at the National Conference on Ideological and Political Work in Colleges and Universities the need to prioritize cultural education in shaping individuals. For higher vocational colleges, the integration of cultural inheritance and innovation with ideological and political work is essential to cultivate virtue and nurture individuals on a new path. The core of laboratory culture education lies in utilizing culture as a medium to positively guide values, life perspectives, and worldviews, thereby advancing laboratory construction. The educational function of laboratory culture construction is mainly reflected in the following three aspects.

3.1. Create an excellent cultural atmosphere

Material culture, as a fundamental aspect of laboratory construction, showcases the laboratory’s temperament and professional characteristics, emphasizing its scale. Since students spend a significant portion of their school time in laboratories engaging in practical training and participating in science and technology competitions, the construction of laboratory culture becomes crucial. By fostering an excellent cultural atmosphere, students can excel in experiments and benefit from the positive influence of the school's cultural environment. This not only improves physical and mental health, encourages innovative thinking, and fosters a love for science but also enhances a sense of belonging, helping students understand the world and themselves. The constant process of self-improvement and enrichment establishes a correct outlook on life, values, and worldviews, equipping students to confidently face life's challenges with rationality and clarity, thereby enhancing their overall abilities.

3.2. Guide correct values

Laboratory culture represents the spiritual consensus between teachers and students, encapsulating a code of conduct that must be followed [4]. The manifestation of laboratory system culture in rules and regulations is crucial for guiding the behavior of teachers and students. Disseminating these rules and regulations to students, coupled with reinforced value guidance, ensures orderly conduct. By enhancing institutional cultural awareness, students adhere to behavioral norms, contributing to their self-education and growth. This fosters the unique cultural characteristics of the laboratory, laying the foundation for cultivating students' comprehensive development and creating an excellent school and study style.

3.3. Promote the comprehensive development of students

University laboratories serve as spaces for innovation and the enhancement of comprehensive abilities. A positive, healthy, and progressive laboratory culture significantly impacts the enthusiasm of both teachers and students within the school, deepening communication, cooperation, trust, and unity. Moreover, laboratory culture embodies the shared beliefs and aspirations of teachers and students, establishing a sense of closeness, trust, and belonging. This silent, pervasive education achieves the goal of nurturing individuals in a harmonious educational environment.

4. Problems existing in the construction of university laboratory culture

The construction of university laboratory culture has emerged as a means for institutions to impart cultural education, yet several challenges persist.

4.1. Problems in the construction of material culture

Firstly, issues arise during the construction of material culture. Some university laboratories face challenges such as poorly planned construction funds and low fund utilization rates, leading to diminished construction efficiency. Secondly, independent work within different majors results in a lack of information sharing, causing the repetition of laboratory equipment purchases and subsequently reducing overall laboratory utilization rates. Thirdly, the layout of laboratories is often impractical, posing safety risks due to inappropriate arrangement of instruments and equipment. Especially concerning are the cases where old teaching buildings are converted into experimental structures, with internal water and electricity arrangements failing to meet fire protection standards. This compromises the safety of storing hazardous materials, chemicals, and flammable or explosive substances. Lastly, a failure to facilitate resource sharing among laboratories exacerbates inefficiencies.

4.2. Problems in the construction of institutional culture

The laboratory system's pivotal role in ensuring normal operation and maintaining laboratory order necessitates a standardized approach. However, despite colleges and universities formulating their own laboratory rules and regulations, many institutions neglect the crucial aspect of system improvement and updates. Reliance on outdated regulations that no longer align with the latest national standards and requirements impedes the progress of laboratory culture construction. Inadequate publicity efforts lead to low awareness among teachers and students, resulting in a weak willingness to learn independently. Consequently, the laboratory system remains more of a formality than an effectively applied framework in actual use.

4.3. Problems in the construction of spiritual culture

Some colleges and universities, particularly those with a short operating history, are still in the early stages of laboratory culture construction. These institutions often lack cultural accumulation in their laboratories and neglect cultural excavation and exploration. In some instances, they might replicate laboratory culture construction from more established universities, which may not align with the goals, developing positioning, and subject characteristics of private universities. This mismatch hinders the integration of laboratory construction development due to a lack of understanding of the functions and connotations of laboratory culture construction [5].

5. An effective approach to building and educating private university laboratories

Given the challenges in the construction of laboratory culture, a comprehensive strategy is proposed to develop spiritual culture, institutional culture, scientific culture, innovation culture, safety culture, and shared culture. Spiritual culture serves as the core, institutional culture as the criterion and scientific culture as the connotation. Simultaneously, innovation culture acts as the driving force, safety culture as the guarantee, and shared culture as the direction, embodying a six-in-one strategy that amalgamates cultural elements, as illustrated in **Figure 2**.

Figure 2. Cultural construction of a six-in-one laboratory

5.1. Emphasizing spiritual culture as the core

The guiding ideology for laboratory construction is rooted in the core concept of spiritual culture, shaping a laboratory that reflects the characteristics of the times and the discipline. Laboratory managers, teachers, and students, as the creators of laboratory culture, must take a leading role. By fostering a harmonious laboratory atmosphere and achieving emotional, cultural, and mission identification, the overall quality of the laboratory can be elevated. Mobilizing and fully engaging the enthusiasm and initiative of laboratory stakeholders is crucial, guiding positive cultural values, and establishing the correct perspective on life, values, and worldviews, thereby promoting laboratory development and mutual growth.

5.2. Upholding institutional culture as the criterion

Institutional culture, a reflection of a school's historical foundation and humanistic characteristics [6], serves as the standard and execution guarantee for constructing university laboratory culture. This culture facilitates the guiding and restraining role of laboratory culture, promoting self-education and growth of teachers and students. Beyond being a collection of rules and regulations, institutional culture should be deeply ingrained, shaping good behavioral habits, standardized conduct, and a positive laboratory image. Private university laboratories should align institutional culture with school goals, development orientation, and subject characteristics. Regular updates to rules and regulations following national standards are essential, along with improvements to various systems, such as scientific and technological information management and internal mechanism reform.

5.3. Elevating scientific culture as the connotation

Scientific culture is the core of laboratory culture construction, requiring adherence to scientific and standardized principles in laboratory construction and operation. Teachers and students must follow relevant laboratory regulations and standardized experimental procedures. Utilizing modern information management technology is essential to enhance the informatization level of laboratory management, ensuring rational resource allocation and utilization efficiency. Big data technology can integrate laboratory process management, promoting the informatization of the experimental course library, instruments, equipment, consumables, and safety management.

5.4. Fostering innovation culture as the driving force

Innovation culture is the soul of laboratory innovation, guiding activities, behaviors, and systems within the laboratory. To inject vitality into laboratory culture, it is crucial to innovate management concepts, highlight key disciplines, and optimize layouts comprehensively. Laboratory management should adapt proactively to development, integrating innovative culture into management, reshaping innovation activities, and fostering a scientific research performance assessment system that encourages daring innovative endeavors [7].

5.5. Ensuring safety culture as a guarantee

Safety culture is integral to laboratory culture, emphasizing the importance of safety management in constructing laboratory safety culture. Establishing safety education, safety management systems, emergency plans, safety learning and examination systems, and basic courses on laboratory safety are essential steps. Disseminating safety knowledge through technology and conducting safety lectures ensures that laboratory safety remains a permanent focus, building a robust long-term safety system [8].

5.6. Embracing shared culture as a direction

In the era of rapid development, laboratory culture must evolve. Shared culture, a key aspect of the expansion of laboratory culture in private universities, underpins the sustainability and diversity of laboratories. Utilizing resources both inside and outside the laboratory through the sharing of equipment, materials, and human resources enhances experimental efficiency and quality. Shared culture broadens the connotation of laboratory culture, enriching its diversity. Knowledge, culture, and experience sharing across different fields promote the intersection and integration of diverse disciplines, fostering the diversified development of laboratory culture [9].

6. Conclusion

The construction of laboratories holds immense significance for the teaching and educational endeavors of private colleges and universities, directly influencing the level of laboratory development and the quality of talent training. By precisely understanding the essence of laboratory culture and embracing the core construction principles of spiritual culture, institutional culture, scientific culture, innovation culture, safety culture, and shared culture, the impact of laboratory culture on talent training, scientific research, innovation, entrepreneurship, technology transformation, and sustainability can be effectively amplified. This approach plays a pivotal role in guiding students to cultivate a correct outlook on life and values, fostering rigorous scientific attitudes, enhancing professional practical abilities, and sparking their capacity for exploration and innovative thinking.

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A Practical Study of Big Data Technology in Computer Network Information Security Processing

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Abstract: In recent years, China has witnessed continuous development and progress in its scientific and technological landscape, with widespread utilization of computer networks. Concurrently, issues related to computer network information security, such as information leakage and virus invasions, have become increasingly prominent. Consequently, there is a pressing need for the implementation of effective network security measures. This paper aims to provide a comprehensive summary and analysis of the challenges associated with computer network information security processing. It delves into the core concepts and characteristics of big data technology, exploring its potential as a solution. The study further scrutinizes the application strategy of big data technology in addressing the aforementioned security issues within computer networks. The insights presented in this paper are intended to serve as a valuable reference for individuals involved in the relevant fields, offering guidance on effective approaches to enhance computer network information security through the application of big data technology.

Keywords: Big data technology; Computer network; Information security

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1. Introduction

At the present stage, big data technology is maturing and evolving, with its application fields gradually expanding. This technology enables the analysis of vast amounts of data, facilitating accurate processing and the prediction of development trends in related areas. Substantial research has affirmed that employing big data technology can optimize the adjustment of methods in processing computer network information security. This optimization serves to safeguard individuals' information and enhance the efficiency of daily work.

Consequently, relevant organizations need to pragmatically assess the situation, determine a well-founded application program for big data technology, and foster a deep integration between big data technology and computer networks. This integration aims to maximize the protection of network information security.

2. Problems in computer network information security

2.1. Virus invasion

The application of information technology in computer networks provides users with convenient conditions for obtaining, processing and applying information. However, it also brings about challenges such as Trojan horses, computer virus invasion, and information leakage. Computer virus invasions, for instance, can result in the loss of crucial internal information, jeopardizing the safe and stable operation of computer systems. In severe cases, it can lead to the paralysis of computer systems and networks, significantly impacting user information security [1]. Furthermore, Trojan horses and computer viruses often operate covertly in the initial stages of invasion, making detection challenging. As the security level of computer network systems decreases, the instances of Trojan horses and computer viruses increase, rendering the computer system non-functional.

2.2. Computer software vulnerability

With the widespread use of information and Internet technology, the diversity of computer software has increased. Unfortunately, some developers lack the necessary design skills, resulting in numerous vulnerabilities in the software. These vulnerabilities create favorable conditions for computer virus invasions and hackers to execute network attacks, elevating the risk of network information theft and posing a serious threat to user information and property security.

2.3. Information loss

The computer network system holds an immense volume of information, and spam is often disseminated through news, emails, pop-up windows, etc. Users' computer systems continuously receive this spam, leading to a reduction in storage space [2]. Simultaneously, spam adversely affects the information security of the computer network, disrupting normal computer system operation and causing the loss of essential information, resulting in immeasurable economic losses for users.

2.4. Operation process and security risks

In the practical application of computer network systems, ensuring information security requires the use of system authority facilities, firewall technology, and other measures. Some users, however, lack security awareness and understanding of computer network security technology. Failure to implement computer password protection, firewall technology, and antivirus software configuration increases the risk of computer network information security. Additionally, users with limited computer operation skills may not grasp the processing and maintenance procedures for computer network information security. Frequent operational errors in this context create security vulnerabilities, significantly amplifying the risk to information security [3].

3. Concepts and characteristics of big data technology

Big data, when appropriately harnessed, transforms into a vast repository of valuable information. Big data technology encompasses the methods of acquiring, processing, managing, and organizing this extensive data, offering indispensable reference information for individuals and enterprises in decision-making processes. The key features of big data technology are outlined as follows: Firstly, big data technology excels in enhancing the speed of data acquisition while simultaneously ensuring effective data management; Secondly, it can judiciously utilize various types of data, generating higher value at a reduced cost; Thirdly, big data technology elevates the quality of data and unlocks its latent potential value. This, in turn, maximizes the security of vital data resources.

4. Strategies for the application of big data technology in computer network information security processing

4.1. Application of cloud computing technology in computer network information security processing

Cloud computing technology, an integral component of big data technology, holds significant application value in computer network information security processing. In the practical realm of computer network information security processing, users can leverage cloud computing technology to scale up the processing of massive data, analyze data values, and swiftly complete the flow of data processing. It is evident that judicious application of cloud computing technology can notably elevate the level of information security processing in computer networks, thereby minimizing the risk of important user information loss.

Currently, various mature cloud computing user service models exist. For instance, Zimory adopts the basic user mode of cloud computing, facilitating the storage and computation of information and data, along with the virtualization processing of data and information. Google Docs, adopting the software service mode of cloud computing, offers users commercial software and diverse application services while ensuring information security. Windows Azure, employing the cloud computing platform service mode, establishes a high-quality operating environment for the system [4].

Simultaneously, personal or enterprise computer systems face limitations in storage space, making it impractical to store various data and information indefinitely. The use of cloud computing technology effectively addresses the issue of insufficient storage space within computers. Users can upload relevant information to cloud storage, thereby enhancing the storage capacity of computer network information and preventing the loss of crucial information. In addition, cloud computing technology significantly improves the accuracy and effectiveness of computer network information processing, contributing to the enhanced application value of big data technology in network information security processing.

In the current stage, cloud computing technology is predominantly distributed or side-by-side in composition. Both approaches effectively integrate network information resources, utilizing grid computing to optimize relevant data and ensure secure processing of network information. As cloud computing technology continues to mature, an invisible data transmission path for remote computer networks is gradually established. This enables the safe, stable, and efficient transmission of data and information stored in the cloud and their corresponding models through wireless networks, thereby ensuring the utmost security of data and information [5].

4.2. Construction of a cybersecurity system platform

Within the realm of big data technology, the functionality of the computing network information security platform has progressively evolved, and its stability has seen significant enhancements. This platform now can centralize the management of computer network information, offering users high-quality security services. The primary functions of the currently widely used big data network security system platform encompass data risk assessment, log analysis, security checks, authentication and authorization, and traffic analysis. Notably, the security review is intricately linked to self-learning technology, and log analysis targets information resources, closely aligning with checking tools, management tools, and basic services.

In the practical application of the network security system platform, its internal risk assessment function can be utilized to ascertain the security status of computer network information. For instance, if assessment results reveal security risks within the computer network information, timely warning information can be issued to users [6]. Concurrently, the big data network security system platform boosts an automatic learning function. Through continuous learning, the platform’s capabilities are progressively refined. During the process of network information security processing and protection, the platform utilizes security operations to ensure information security, mitigating issues such as information theft.

The application of big data technology optimizes the processing of diverse types of computer network information, identifying data that poses a threat to the network. Effective measures can then be implemented to address these threats, ensuring information security. Moreover, big data technology facilitates the establishment of a network security system platform service background. This background, through the security defense system, efficiently processes massive data, guaranteeing information security. Additionally, the background offers users intelligent services and information technology services. Leveraging security checks, traffic analysis, log information, and other basic functions, it achieves effective management of various data types, ultimately enhancing the overall effectiveness of network information security processing.

4.3. Big data collection technology

Big data collection technology encompasses various components, including big data pre-processing technology, big data storage technology, big data analysis technology, big data cleaning technology, big data integration and transformation technology, and big data statute technology, among others. The judicious application of these technologies enables the high-quality collection and processing of raw data from computer networks. Additionally, it facilitates the integration and organization of data under specific protocols, allowing for the storage and analysis of various data information. This comprehensive approach ensures the information security of computer networks.

Concurrently, the thoughtful application of big data collection technology establishes favorable conditions for the development of cloud computing technology. By engaging in pre-processing and storage of data, it provides essential data support for the advancement of cloud computing technology [7].

4.4. Big data storage technology

Big data storage technology plays a pivotal role in encrypting and storing information transmitted through computer networks, ensuring the security of stored data. In contrast to traditional modes of computer network information storage, big data storage technology boasts characteristics of being unstructured and real-time. This ensures the timeliness and security of data storage, alongside an expanded storage range, significantly enhancing the security of big data storage.

Furthermore, big data storage technology relies on the support of data backup technology. The collaborative application of these two technologies allows for the storage of essential data resources on backup servers. This proactive approach helps prevent Trojan horse or computer virus attacks on computer systems resulting from data loss, thereby ensuring data security.

4.5. Data key technology

Data key technology encompasses asymmetric key technology and symmetric key technology, both of which contribute to computer network information security processing through distinct methods. Serving as an effective privacy protection measure, data key technology encrypts key data information within the computer system. This technology facilitates the encryption of big data keys, enabling information retrieval and repair after data loss. Consequently, data key technology enhances the information security protection level of computer networks.

In addition, the application of data key technology alleviates the pressure on computer network information security processing. Integrated systems streamline the data encryption process, efficiently overseeing computer network information security, preventing unauthorized intrusion, and ensuring the security of computer network databases.

4.6. Hadoop technology

Hadoop technology presents clear advantages in the realm of computer network information security processing. With its integrated capabilities and data management functions, Hadoop technology can address diverse requirements for the storage and security processing of different types of computer network data. It effectively controls the data management process, reducing the likelihood of errors.

Simultaneously, Hadoop technology allows for the prioritization of processing based on actual needs. By aligning with the specific type of network data information, it determines priority levels. Through effective linkages, Hadoop technology maximizes the protection of network information security [8].

5. Conclusion

Currently, computer networks are ubiquitous in China, and the challenges associated with network information security are increasingly pronounced. Therefore, there is a pressing need to continuously optimize and enhance security protection technologies to ensure high-quality processing of network information security.

Big data technology, with its capability to process massive amounts of information and manage data storage and analysis, holds exceptional value in the realm of computer network information security processing. It is recommended that relevant organizations align their strategies with the current situation to formulate a well-considered application plan for big data technology. Additionally, summarizing pertinent experiences gained in the practical application of this technology can contribute to the ongoing efforts to safeguard the security of data information.

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Manifold Structure Analysis of Tactical Network Traffic Matrix Based on Maximum Variance Unfolding Algorithm

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Abstract: As modern weapons and equipment undergo increasing levels of informatization, intelligence, and networking, the topology and traffic characteristics of battlefield data networks built with tactical data links are becoming progressively complex. In this paper, we employ a traffic matrix to model the tactical data link network. We propose a method that utilizes the Maximum Variance Unfolding (MVU) algorithm to conduct nonlinear dimensionality reduction analysis on high-dimensional open network traffic matrix datasets. This approach introduces novel ideas and methods for future applications, including traffic prediction and anomaly analysis in real battlefield network environments.

Keywords: Manifold learning; Maximum Variance Unfolding (MVU) algorithm; Nonlinear dimensionality reduction

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1. Introduction

Since the Gulf War, the nature of warfare has transitioned from traditional large-scale mechanized conflicts to localized warfare under high-tech conditions. With the rapid advancement of technologies such as computers, network information, and artificial intelligence, modern warfare has become increasingly informatized, networked, and intelligent. The shift in the form of modern warfare from platform-centered to network-centered is a significant change. Unlike platform-centered warfare focused on weapon platforms, network-centered warfare is a networked and information-based integrated form centered on the network. It stands as the fundamental and crucial combat style for local wars under information technology conditions, integrating intelligence, command, communication, computers, electronic warfare, information warfare, combat support, and firepower strikes. This approach constructs a network-centric battlefield environment, connecting various combat units, weapon platforms, and information systems in the battlefield through the network. It achieves continuous improvement in intelligence sharing, enhances battlefield situational awareness, accelerates combat decision-making and commanding, and accomplishes almost real-time combat coordination for tactical purposes. The data link network facilitates space-time cooperative operations among various combat units in systematic and integrative warfare and serves as the infrastructure for constructing a network-centric battlefield environment. It also acts as the neural center of the network-centric warfare system.

With the rapid development of military science and technology, the level of informatization and intelligence of modern weapons and equipment is rapidly advancing. The number and types of equipment that can be connected to the tactical data link network will increase exponentially, leading to a more complex topology and data traffic characteristics of the network. Data link network traffic acts as the carrier of information, flowing like the "blood" in the large-scale and complex battlefield network environment. In the face of this increasingly complex network environment, understanding how to process and analyze battlefield network communication traffic data, extract traffic characteristics, perceive the network situation, detect anomalies, and predict network traffic is a crucial prerequisite for building a more robust and real-time battlefield network.

Currently, most analyses and research on network traffic data are primarily conducted on a single link in isolation [1-5]. However, the emergence of the traffic matrix provides an opportunity to analyze network traffic data characteristics from the perspective of the entire network [6]. Research revealed that data traffic on different links in a network is not independent; instead, it often exhibits similar traffic characteristics [6]. Lakhina *et al.* employed a linear analysis method based on the Principal Component Analysis (PCA) algorithm [7]. As the complexity of the network structure increases, data traffic may exhibit more complex nonlinear characteristics. Therefore, this article utilizes a nonlinear dimensionality reduction algorithm to conduct dimensionality reduction analysis of complex battlefield networks, providing a new idea and method for network situation awareness and data analysis in future systematic operations involving complex battlefield networks.

2. Basic theory

This section primarily introduces the mathematical theory related to manifold learning.

(1) Topology: Let τ be a subset family of the non-empty set X. If τ satisfies the following constraints:

- $X, \emptyset \in \tau$;
- if $A,B \in \tau$, then $A \cap B \in \tau$;
- if $\tau_1 \in \tau$, then $\cup_{A \in \tau 1} A \in \tau$;

then is called a topology of X.

(2) Topology space: If τ is a topology of the set X, then the pair (X, τ) is called a topological space.

(3) Homeomorphism: Let X and Y be two topological spaces. If $f{:}X \to Y$ is one-to-one mapping, f and $f^{-1}: Y \to X$ both are continuous, then f is called homeomorphic mapping or homeomorphism.

(4) Hausdoff space: Let (X, τ) be topology space, $\forall x, y \in X, x \neq y, \exists U_x$ and U_y, s.t. $U_x \cap U_y = \emptyset$, then (X, τ) is a Hausdoff space, where U_x and U_y are the neighborhoods of x and y.

(5) Manifold: Let X be a Hausdoff space, $\forall x \in X$, there exists an open set neighborhood U which is homeomorphic to the Euclidean space $\mathbb{R}^D$, then X is a D-dimensional topological manifold, referred to as a D-dimensional manifold.

(6) Manifold learning: For data set $X = \{x_1, x_2, \cdots, x_N\} \subset \mathbb{R}^D$, assume that any point in X can be generated by $Y = \{y_1, y_2, \cdots, y_N\} \subset \mathbb{R}^d$ through a nonlinear mapping. The goals of manifold learning are:

- To get $Y = \{y_1, y_2, \cdots, y_N\} \subset \mathbb{R}^d$, which is the low-dimensional coordinates of X;
- To get $f^{-1}{:}\mathbb{R}^D \to \mathbb{R}^d$, which is a nonlinear mapping from the high-dimensional input space to the low-dimensional output space.

3. Maximum variance unfolding algorithm

3.1. Brief introduction

Manifold learning assumes that high-dimensional input data are approximately situated on a low-dimensional manifold embedded in the high-dimensional space. The global feature preservation method calculates low-dimensional coordinates by performing eigendecomposition on the similarity inner product matrix, constructed from the global similarity matrix, aiming to retain the global geometric features of the output data in the low-dimensional space. Typically, this algorithm involves three steps: (1) constructing a neighborhood graph from the input data; (2) building an inner product matrix based on the global similarity measure matrix; (3) conducting eigenvalue decomposition of the inner product matrix to derive the low-dimensional embedding coordinates of the input data.

Maximum variance unfolding (MVU) is a manifold learning algorithm proposed under local isometric constraints [8-11]. Its fundamental concept is to "expand" non-adjacent data as far apart from each other as possible while maintaining the distance between neighboring points on the neighborhood graph unchanged. For instance, envision a string of curly necklaces as a one-dimensional manifold embedded in a two-dimensional space. Each data point in the high-dimensional space represents a node on the necklace. The MVU idea is akin to unfolding the "necklace" in the low-dimensional space, illustrated in **Figure 1**. Theoretically, the process of "unfolding" high-dimensional data using MVU can be formulated as a quadratic programming problem, where $max \sum_{ij} \|y_i - y_j\|^2$ which satisfies the following constraints

(1) $\|y_i - y_j\|^2 = \|x_i - x_j\|^2$ where x_i and y_j are neighbors of each other

(2) $\sum_i y_i = 0$

where constraint (1) is a local isometric constraint, ensuring that the Euclidean distance between neighboring points remains unchanged after dimensionality reduction, while constraint (2) is used to eliminate the centralization constraint of the translational degree of freedom [12,13]. By defining the Gram inner product matrix $K_{ij} = y_i y_j$, the above non-convex optimization quadratic programming problem can be transformed into a convex optimization semidefinite programming (SDP) problem, where $maxtr(K)$ satisfies

(1) $K_{ii} - 2K_{ij} + K_{jj} = \|x_i - x_j\|^2$, where x_i and y_j are neighbors of each other

(2) $\sum_{ij} K_{ij} = 0$

(3) $K \geq 0$

where (3) is a positive semi-definite constraint, which ensures that this SDP has the optimal solution. By solving this SDP problem, the Gram matrix K can be obtained, and the d-dimensional embedding coordinates can be represented by the eigenvectors corresponding to the d largest eigenvalues of K.

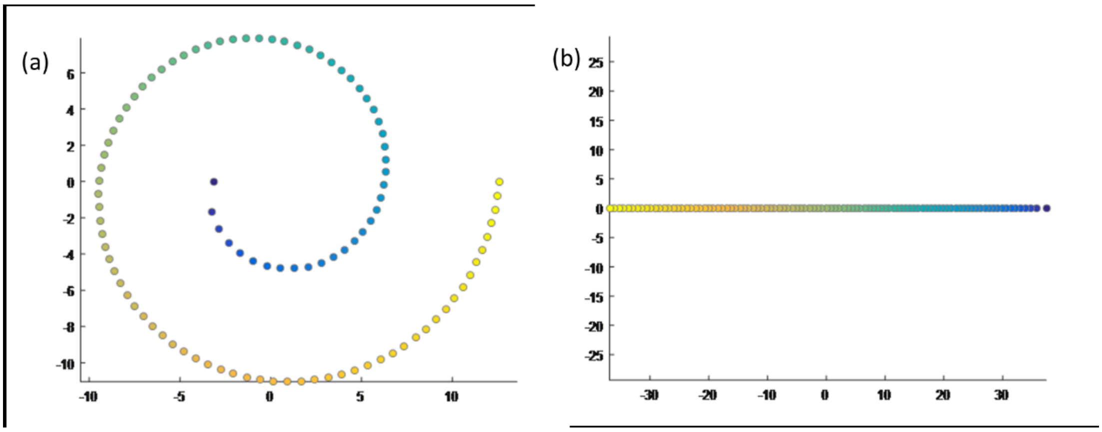

Figure 1. (a) The two-dimensional "necklace" data; **(b)** MVU embedding result from "necklace" data

3.2. MVU algorithm process

(1) Neighborhood graph construction by using the k-NN method or ε-ball method.

(2) SDP: The objective function is constructed under local isometric constraints and centralization constraints, and converted into a SDP problem. Then the SDP problem is solved to obtain the positive semi-definite Gram matrix .

(3) Spectral decomposition: Perform eigen-decomposition of the Gram matrix to obtain the low-dimensional coordinates.

The embedding results of MVU on public data sets are shown in **Figure 2**.

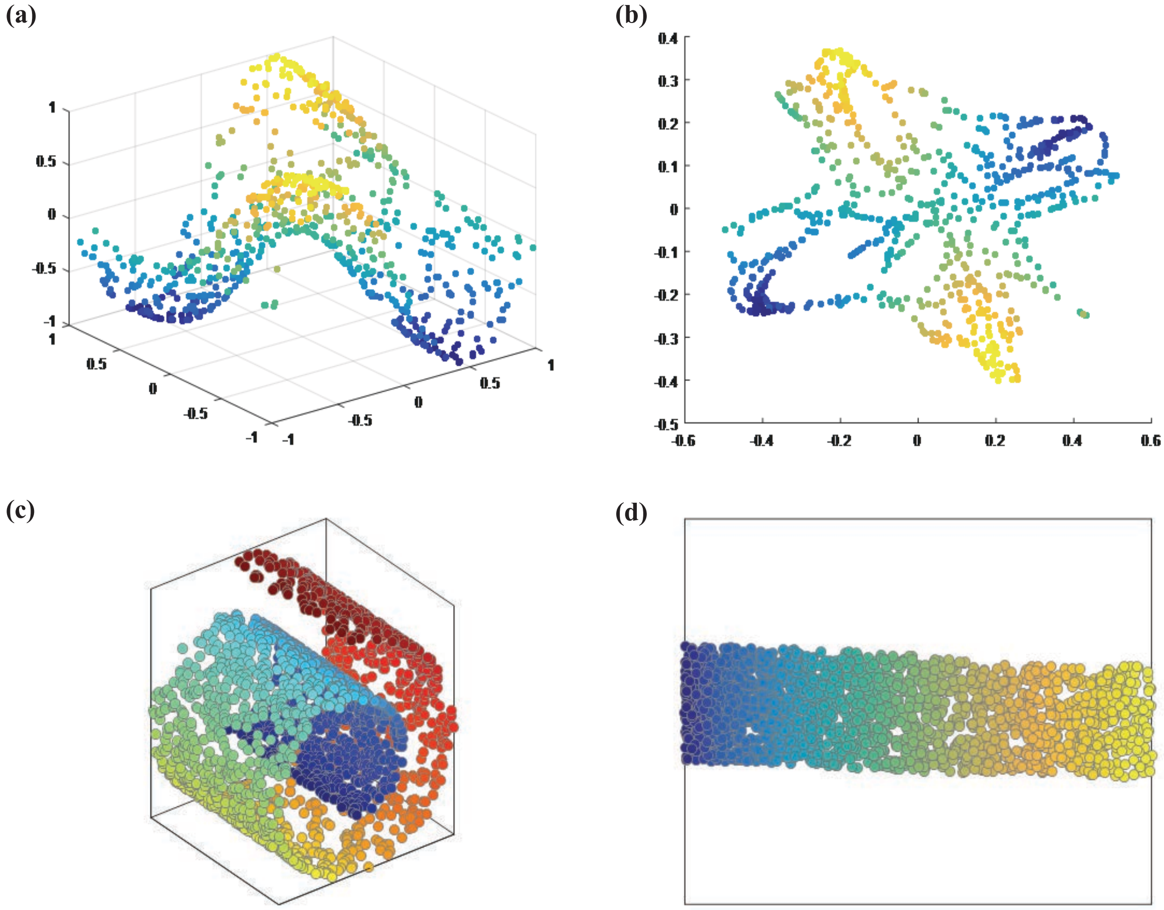

Figure 2. (a) TwinPeak data set; **(b)** TwinPeak data set embedding result by MVU; **(c)** SwissRoll data set; **(d)** SwissRoll data set embedding result by MVU

3.3. Algorithm analysis

MVU is a global manifold learning algorithm based on isometry. If there exists a subset of the Euclidean space equidistant from the manifold where the high-dimensional input data is situated, MVU can accurately restore the low-dimensionality of the high-dimensional input data. Additionally, because MVU does not require the calculation of geodesic distance between input data, it can yield genuine dimensionality reduction results even for non-convex data sets. However, the MVU algorithm has notable drawbacks. Firstly, the time complexity and space complexity of MVU for solving the SDP problem are both $O((kN)^3)$, and the time complexity of eigenvalue decomposition of the Gram matrix during the solution of low-dimensional embedded coordinates is $O(N^3)$. Consequently, the substantial computational complexity significantly hampers the application of the

MVU algorithm on large-scale data sets. Secondly, due to the stringent local isometric constraints, the MVU algorithm may perform poorly due to "short-circuit edges" resulting from noise data during the construction of the neighborhood graph.

4. Dimensionality reduction analysis of tactical network traffic data

4.1. Network traffic matrix modeling

Let Ω represent the non-empty set of all nodes in the network, with $|\Omega|=N$. The flow matrix can be naturally represented by a three-dimensional non-negative hypermatrix $X(t)$, where each element is denoted as $X_{i,j}(t)$. Each element in the traffic matrix signifies the traffic measurement value from the source node i to the destination node j within the time period $(t, t+\Delta t) \subset T$, covering the entire measurement period. Real-time measurement of the traffic matrix size is challenging, so the algebraic mean of the traffic at a discrete time interval Δt is typically used as the measurement value for that period. For different combat missions, the time interval can be chosen based on the specific circumstances. In a decentralized battlefield network consisting of N combat units, the traffic matrix dimension obtained in any observation period is N^2. Consequently, the dimension of traffic matrix data acquired in one measurement period will be 225 in a network comprising 15 nodes. Directly analyzing such a high-dimensional traffic matrix poses challenges in terms of computational and storage complexity. Therefore, the MVU algorithm is employed for dimensionality reduction on the high-dimensional network traffic matrix data to facilitate storage and analysis.

In this paper, we utilize public traffic matrix datasets to simulate real battlefield networks, sourced from http://www.cs.utexas.edu/~yzhang/research/AbileneTM. This dataset collection spans 6 months of Internet traffic matrix data from the Abilene backbone network, comprising a total of 24 data files, with each data file containing 2016 traffic matrices. The network consists of 12 PoP points, making each traffic matrix 144-dimensional, with a sampling interval of 5 minutes and data units measured in bytes.

4.2. Intrinsic dimensionality and residual variance analysis

Determining whether the traffic matrix possesses low-dimensional features is a prerequisite for subsequent dimensionality reduction analysis. Lakhina *et al*. observed that each data flow in the traffic matrix can be expressed as the weighted sum of a small number of eigenvalue flows [7]. As depicted in **Figure 3**, a significant portion of the traffic variance is determined by the first few (5 to 10) eigenvalue flows, indicating that the dimensions of these high-dimensional traffic matrices are considerably lower than the number of PoP pairs in the network.

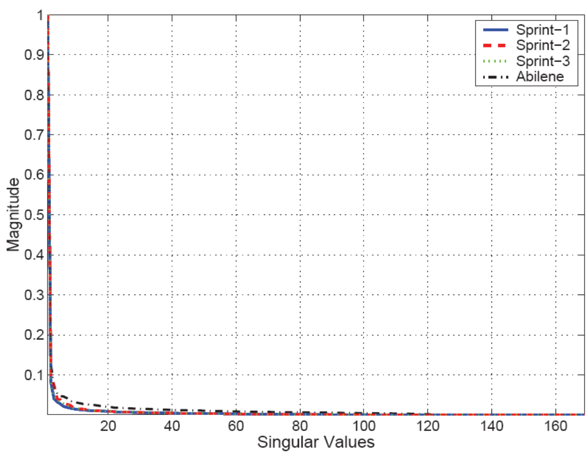

Figure 3. Dimensionality analysis on traffic flow data by PCA

Tenenbaum *et al*. employed the residual variance method to analyze the intrinsic dimensionality of high-dimensional input data [12]. We applied MVU to the public traffic data set, and the results of the residual variance results are presented in **Figure 4**. The intrinsic dimensionality can be identified by identifying the "elbow" point where the curve ceases to significantly decrease with added dimensions. As demonstrated in **Figure 4**, the "elbow" points of the residual variance curves for all four data sets occur at d = 5, signifying that their intrinsic dimensions are much smaller than their original dimensions.

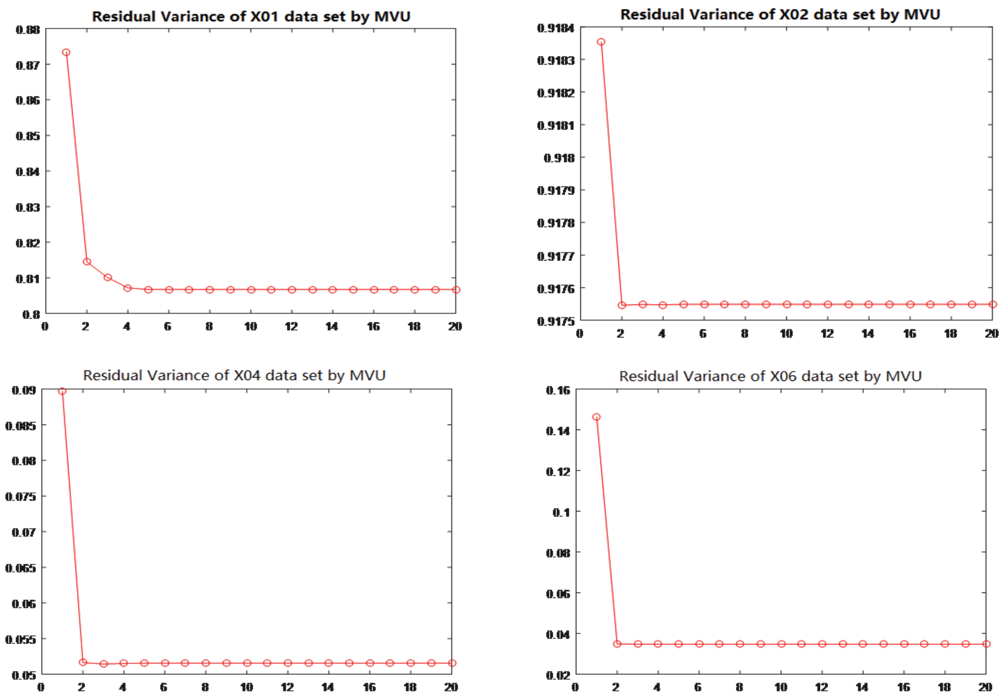

Figure 4. Residual variance results of the open traffic datasets by MVU

The low-dimensional nature of the network traffic matrix is attributed to its spatial correlation. The network comprises edge networks and core networks, and the traffic of different nodes in the core network may originate from the same edge network. This similarity in variation patterns among the different nodes results in a more condensed low-dimensional representation of the high-dimensional traffic matrix.

4.3. Low-dimensional structure analysis

To gain a more intuitive understanding of the low-dimensional structures within the traffic matrix, this section delves deeper into the analysis of the MVU three-dimensional embedding results of the traffic matrix data.

For visual clarity, we present the three-dimensional embedding result of datasets X01, X06, X11, and X18 in **Figure 5**. These four datasets exhibit diverse structures in the low-dimensional embedding space, illustrating relationships among global network-wide traffic during sampling time intervals. The embedding result of dataset X11 demonstrates nearly linear characteristics, suggesting a linear variation pattern and features within the corresponding network traffic. In the results of datasets X01 and X18, some isolated points are noticeable, possibly linked to abnormal situations in the network. Through this analysis, it becomes evident that various network traffic matrix datasets showcase distinct structural characteristics in their low-dimensional embedding space.

By utilizing manifold learning methods to reduce the dimensionality of high-dimensional traffic matrix data and analyze low-dimensional structures, valuable insights can be gleaned. This approach enables the extraction of information such as traffic trends or anomalies, providing a novel method for analyzing internet traffic from a network-wide perspective.

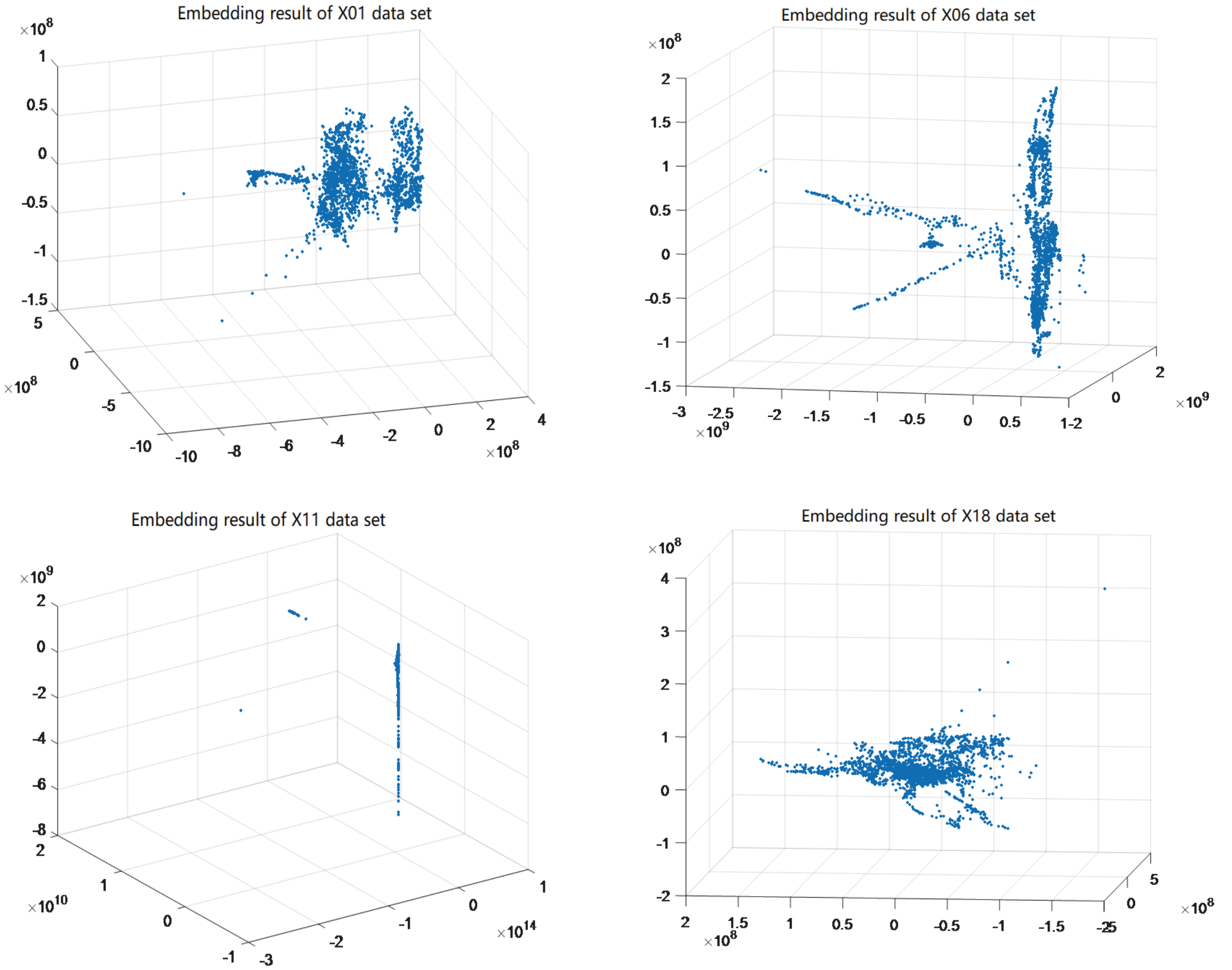

Figure 5. MVU embedding result of different traffic datasets

5. Conclusion

In this paper, we applied the MVU algorithm to open datasets to analyze the low-dimensional structure of network traffic. The experimental results demonstrate the validity of our approach. However, the MVU algorithm still faces challenges due to its high complexity and weak robustness, thereby restricting its application to large-scale, noisy datasets. In future work, our emphasis will be on enhancing the computational efficiency and robustness of the MVU algorithm.

Disclosure statement

The authors declare no conflict of interest.

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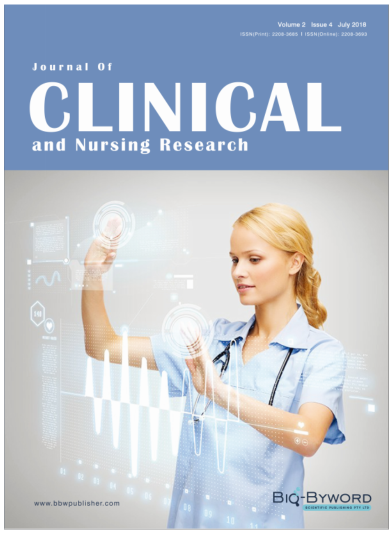

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