IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received August 20, 2019, accepted September 21, 2019, date of publication October 3, 2019, date of current version October 30, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2945330

A Structural Design and Interaction Algorithm of Smart Microscope Embedded on Virtual and Real Fusion Technologies

KANG WANG, ZHIQUAN FENG, JIAN LI, AND RUI HAN
Department of Information Science and Engineering, University of Jinan, Jinan 250022, China
Shandong Provincial Key Laboratory of Network-Based Intelligent Computing, University of Jinan, Jinan 250022, China

Corresponding author: Zhiquan Feng (ise_fengzq@ujn.edu.cn)

This work was supported by the National Key Research and Development Program of China under Grant 2018YFB1004901.

ABSTRACT The microscope is an important teaching tool in secondary school biology. This important equipment needs to be understood and mastered through biological experiments. However, in actual experimental teaching in China, microscope samples are difficult to produce, preserve and share, and the implementation status is not ideal. These conditions seriously affect student enthusiasm and require additional participant labor. Moreover, they hinder teachers' evaluation of experimental learning. Thus, this paper constructs a smart microscope physical interaction kit for secondary school biology experiments. First, the main components of the traditional microscope are replaced by a variety of different sensing elements, which are 3D printed. Then, a novel multichannel information integration strategy based on visual, auditory and tactile information is proposed to manage different channels of information, to understand the user's operational intent and to organize reasonable interactions (including the display of real-time adjustment effects). Then, we propose a navigational interaction paradigm based on multimodal intent understanding, aiming at reminding users of invalid behavior and providing necessary operational guidance for users, thus achieving the purpose of intelligent interaction and intelligent experimental teaching. The experimental results show that the proposed microscope kit, multichannel integration strategy and navigation interaction algorithm not only imbue microscopy experiments with the characteristics of intelligent interaction but also stimulate student enthusiasm and help the evaluation of experimental learning. We find that these capabilities are well received by users.

INDEX TERMS Intelligent microscope, user intention understanding, multichannel integration, intelligent interaction, navigation interaction.

I. INTRODUCTION

The microscope is an important tool to observe and understand the microscopic world. It is an indispensable instrument in chemistry, biology and histology. Therefore, microscopy-related teaching experiments are very important in junior high school, senior high school and university experimental teaching. In the primary school stage, microscopes are typically used to observe microscopic aspects of the physical world, such as pollen grains or bee tentacles. Most of these experiments are conducted to stimulate students' interest in understanding nature and the microscale world. In the junior high school stage, we begin to build a complete knowledge system, including the structural knowledge and use of the microscope, and students might observe the onion epidermis or human oral epithelial cells. These simple observations of cell alignment expand students' understanding of the different levels of life in cells, tissues, organs and even individuals. According to a survey, in some senior high schools with certain curricula, teachers organize students to observe the distribution of DNA and RNA and the morphology of chloroplasts and mitochondria. These experiments push microscopy observation to the subcell level and allow students to explore life more deeply. However, in most ordinary schools, the following problems are common in the practice of microscopy teaching. First, most secondary schools in China are not equipped with a

The associate editor coordinating the review of this manuscript and approving it for publication was Hao Ji.

sufficient number of microscopes to ensure that the relevant experiments can be performed. Especially in the practical learning stage of junior high school students who have a comprehensive understanding of microscopes and use them, it is common that the lack of microscopes leads to the failure of experimental courses to be open to all interested students. Second, preparation of sample materials and repeated adjustment of microscopes consume a lot of classroom time, which may make it impossible for students to acquire clear sample images during limited class times. Third, the traditional experimental method cannot achieve sample image sharing and information enhancement. Students can see only the clear sample images they have adjusted, and there is no way to compare these images with those of other students efficiently and conveniently. This situation is not conducive to the sharing of information between students or to stimulating inquiry-based learning discussions between students. Fourth, traditional experimental methods lack interactive communication between teachers and students. It is difficult for teachers to supervise and evaluate the students' experimental learning situation because of the challenges involved in checking individual student results to give guidance.

Therefore, this paper provides a virtual microscope physical interaction kit for secondary school experiments. Through the design of software and hardware, combined with the corresponding information technology, the virtualized visualization of the microscopy observation effect is realized. The main advantages of this paper are that it not only solves some of the bottleneck problems and related constraints mentioned above, which are difficult to solve in microscopy classes in secondary schools, but also imparts typical features such as intelligence and interactivity to experimental microscopy methods. On the one hand, we use virtual fusion technology to enhance the information of user observations, which is beneficial to users' random exploration of the process, mechanism and principle of experimental phenomena. On the other hand, through physical operation, the operating experience and related experimental skills under real microscopy conditions can be obtained.

II. RELATED WORK

A. PROBLEMS AND SOLUTIONS OF TRADITIONAL MICROSCOPE IN TEACHING ENVIRONMENT

Microscopes have been the primary method of structural analysis of organisms at the cellular level since the 19th century. There are many detailed descriptions of the structure and development of microscopes in the network, which will not be repeated here. Advances in microscopy technology have prompted researchers to identify the relationships among the functional structures of cells, tissues and organs; furthermore, microscopy has become an indispensable key technology in education and teaching, especially in the fields of biology, histology and pathology. However, in various fields, the use of conventional microscopes can lead to problems. For example, in histology education, traditional microscopes cause many problems in medical schools. First, specialized microscopes are very expensive and require substantial physical space for storage and use in laboratories. Second, glass slides must be replaced regularly. The facility management staff of hospitals, for example, faces a large burden [1].

In the study of pathology, pathologists must make samples of pathological tissue slices, which are usually unique to each sample, so the complexity and difficulty of teaching this field are often difficult to accommodate with pathological cell samples. Therefore, some alternative strategies to address these limitations have received research interest, such as the use of virtual microscopes [2], [3]. Reference [1] designed and implemented a virtual microscope client/server database system that provides a realistic simulation of high-power optical microscopes. In addition, two versions of virtual microscope server software were implemented and designed to solve the problem of storing and processing a very large amount of microscopy image data. The system is used for dynamic telepathology research, which reduces the cost of equipment and solves the problem that pathological cell samples are difficult to share. Furthermore, [4] confirmed the convenience of a virtual microscope in Web-based applications for organizational pedagogy.

Moreover, special problems exist in the study of microscopy in primary and secondary schools. Mirko and Antonio [5] investigated the use of microscopes in 73 primary and 30 secondary schools in Dalmatia County. The results showed that 94% of the schools have at least one single optical microscope. However, only 39% of teachers use microscopes for complete teaching every school year, and 61% only use them occasionally. Furthermore, 53% of the teachers reported that the main reason that they seldom used microscopes in teaching was the lack of sufficient microscopes for high-quality teaching. The teachers' low participation in microscopy education was found to arise from their apprehension that they could not organize microscopy teaching and operation reasonably well under the constraints of limited time and motivation.

This phenomenon is also widespread in China. Because most township junior high schools do not have enough microscopes for experimental teaching, students generally use microscopes in groups. The skilled use and understanding of microscopes to obtain experimental results are challenging. Moreover, traditional microscopes require substantial experience to prepare samples and adjust the microscopes, and this process is time-consuming. Therefore, for teachers in township junior high schools, it is impossible to ensure that students can master the relevant experimental operations with limited classroom time and resources. In addition, Zeng Guoyong and others obtained other reasons for the inefficiency of the experimental classroom through investigation [6]. Some students reported that teachers emphasized theory over practice in experimental classes, which resulted in a shorter time for practical operation. Some students also found it difficult to adjust to the new technique of using a microscope and reported that it took many attempts to obtain a good observation sample, increasing the challenging of completing all the necessary work in a short time. With the rapid development of information technology, many new technologies and strategies have been proposed to solve the problems of traditional microscopy in different fields. In addition, new and more powerful types of microscopes have been developed, such as virtual microscopes, electron microscopes, metallographic microscopes, and 3D microscopes.

Several tentative methods have been proposed to address these problems in the secondary school teaching environment. Reference [7] introduced teaching methods involving the combination of experiments and microcourses secondary schools to help students correctly understand the skills to operate and adjust a microscope. A method of learning the technique of scanning electron microscopy by using an e-learning platform, integrating online instructions, simulating virtual experiments, and using multimedia tools to present relevant information is proposed in [8]. In addition, some software for experimental teaching in secondary schools has been developed. For example, the virtual experiment teaching platform developed by Nobook [9] supports students in conducting microscope experiments on tablet computers and electronic whiteboards by touch screens. However, at present, problems remain regarding insufficient microscopy equipment in secondary schools; the challenges of adjusting the tool in a limited time, acquiring and saving samples, and sharing experimental results; and the low participation of teachers in secondary schools experimental microscopy classes. The solutions mentioned above do not satisfy the need for actual user interaction. Indeed, for students, learning about and understanding microscopy is inseparable from actual hands-on operation. This interaction is not achievable through mouse clicks and touch screen operations. Therefore, for the experimental microscopy teaching of secondary schools students in China, there is an urgent need for a new type of microscope with interactive function. This tool needs to have certain characteristics of a traditional microscope while satisfying the needs of easy adjustment, straightforward sample preparation, ease of observation, low cost and easy accessibility. Obviously, this concept necessitates a smarter microscope. First, the tool must have a relatively strong interactive ability, must integrate the information input by the user, and must understand the user's intention; second, it must correct and guide the user's behavior according to his or her intention. Obviously, it is difficult to realize such an intelligent microscope by relying on traditional single-channel human-computer interaction. Even if this technique can be realized, it often fails to achieve the desired effect. On the one hand, although the information input by a single channel is accurate and intuitive, it risks losing user attention. On the other hand, the information of a single channel is insufficient to cover all aspects of the user's information, resulting in the lack of interactive experience in the experiment. Consider, for example, the widely used mouse and keyboard combination or the graphical interface interaction based on brush strokes; if intelligent microscopy is implemented on the basis of this interaction, users will easily lose the sense of experience in the actual operation process. The multichannel interaction method [10], [11] can address this limitation because under the natural interaction condition, the multichannel interactive system needs to integrate the information of different channels and must accurately evaluate what the user wishes to do. It is possible to accurately feedback user behavior, so the key to natural interaction in multichannel human-computer interaction is the accurate understanding of user intent. Therefore, the design of this new microscope is based on multichannel interaction and user intent understanding, which is necessary to achieve intelligence.

B. MULTICHANNEL HUMAN-COMPUTER INTERACTION METHOD

Multichannel human-computer interaction is a very dynamic and extensive research field. In recent years, many scholars have proposed multichannel information processing methods, mainly multichannel fusion strategies or models to construct a naturalized human-computer interaction environment. In general, multichannel information fusion can be divided into prefusion and postfusion according to the chronological order of occurrence; according to the processing method, these techniques can be classified as either rule-based fusion or statistical (machine-learning-based) fusion [12], [13]. There are also studies that classify the associated relationships into information complementation, information exclusion, and information redundancy based on the relevance of multichannel information. Then, according to the information characteristics, fusion is carried out separately [14]. In the appeal fusion method, the widely used information fusion computing model is based on statistics and machine learning. For example, the Bayes decision model [15], because it can infer the optimal decision under partial observation conditions based on incomplete information, often shows certain advantages in multichannel information integration analysis and decision making. This technique is very well applied in robot attitude estimation and obstacle avoidance [16], emotional understanding [17], multisource sensor information alignment and observation data analysis [18]. Alternatively, the large-scale deep neural network model based on a single-channel convolutional neural network [19], [20] also attempts to integrate multiple multichannel information from the data layer, model layer and decision layer to achieve multitask learning [21] and cross-modal learning [22]. In addition, many other models are used for multichannel information fusion, such as multilayer support vector machines (SVMs) [23], [24], decision regression trees, random forests and other methods. Moreover, many scholars have applied the appeal model method to practical engineering, such as simulating human writing of text based on the dynamic Bayes model [25], understanding gestures and gestures based on the Markov decision process [26], and SVM-based identity differentiation [27].

This paper discusses how to design and implement a smart microscope from the perspective of multichannel information integration for user intent understanding. In addition, a virtual microscope physical kit for secondary school experiments was designed and implemented. Based on this work, a new multimodal user intent understanding algorithm is proposed that organizes auditory, visual and tactile information and infers the user's intention. To achieve intelligent interaction, the monitoring, correction and evaluation functions of user operation behavior are added in the design process.

III. INTELLIGENT MICROSCOPE DESIGN FOR MULTIMODAL INTERACTION

In the process of adjusting the traditional microscope, it is necessary to move the sample to find the most suitable viewing angle, to adjust the coarse focus helix and the fine call helix to change the sample clarity, and to switch the converter to enlarge the sample to be observed. Through the combination of the appeal operation process, the user can observe the clear sample image under the microscope. For smart microscopy, users also need to go through the process of appeal adjustment in order to obtain the ideal observation effect. Because it is necessary to ensure that middle school students learn and master the process and steps of adjusting the microscope, so the design of intelligent microscope is a high simulation of traditional microscope. However, the difference is that on the one hand, intelligent microscopy simplifies the adjustment process of traditional microscopy, reduces the difficulty of adjustment and optimizes the observation effect through the design of different sensor elements and multimodal interaction framework. On the other hand, the functions of voice navigation, intention understanding and image preservation and sharing are added in the adjustment process, which makes the use of microscope more intelligent. Moreover, compared with electronic microscopes [28] and digital microscopes [29] with preservation functions, intelligent microscopes do not require higher production costs.

The design of an intelligent microscope is a typical multimodal information acquisition and integration process. For students, voice and visual presentation are natural interactions. Deep learning [30] technology improves the accuracy of speech recognition, speech conversion into text information and speech synthesis technology and increases the flexibility and intelligence of the human-computer interaction process. In terms of image processing, the intelligent microscope can accurately identify different sample tags by means of image processing technology, calculate the position of the tracking points in real time, and control the movement of the sample images according to certain rules.

A. MULTIMODAL INTERACTION DESIGN OVERALL ARCHITECTURE

In terms of practical design, the speech and action behaviors in the interaction process are spatially separated and temporally dispersed. During the operation, the content range of the voice input is narrow, and the adjustment of the microscope is minimal. Therefore, it is not particularly suitable to use the framework of deep learning to complete the information of different channels. Thus, in the design of intelligent microscopy, speech recognition [31], video sequence target point tracking [32], dialogue intention understanding [33] and other methods are adopted. Multimodal hybrid management based on the complementary processing of multimodal information, fusion processing, and individual processing is the core element. Fig. 1 shows the overall framework structure with multimodal interactions.

The overall process of multimodal interaction can be divided into multimodal input and perception, integration of multimodal information, and interactive applications based on integration results. In the multimodal input and perception process, the microphone is used to obtain the user's voice information, and the user's operation behavior is detected by touch and vision. The tactile information is derived from a rotation sensor and a touch selector, wherein the rotation sensor is used to capture the rotation of the coarse quasifocus spiral, and further, the user's adjustment intention can be inferred. There are two types of touch selectors, one for defining different operating behaviors of the user and the other for changing the magnification of the converter. Visual information is obtained through ordinary cameras. The common camera we used has two tasks, one for the identification of sample types and the other for detecting sample movement. In the following sections, we show how an observation sample is identified and used to detect movement. The design of the multichannel information integration module [34], [35] is the key to multichannel interaction. The system is similar to a simple operating system that receives information from different channels, integrates the received information, and determines whether different operational actions are performed in sequence or concurrently. In addition, the effective information in the integration process is processed for the reasoning of the user's partial intent, thereby completing the intelligent interaction with the user. Throughout the multichannel information integration module, based on the operational behaviors used and the operational settings of the microscopy experiments, we provide informative simulations of the adjustments that occur in real experiments. On the one hand, the multichannel integration design ensures the connection between the user's operation and the real experimental effect simulation so that the intelligent microscope has the ability to understand the user's intention; on the other hand, the intent of the user is at least partially reasoned according to the reasoning results and the operation effect. We identify unreasonable user actions and prompt for the necessary experimental steps to achieve a more effective interaction. In the interactive application layer, the effect is presented mainly through visual display and auditory guidance, and the visual presentation enables observation of the sample image under the microscope through a mobile phone display screen. A description of the microscope operation is given later. Without loss of generality, we suggest that the multimodal interaction framework can be used in many interactive scenarios.

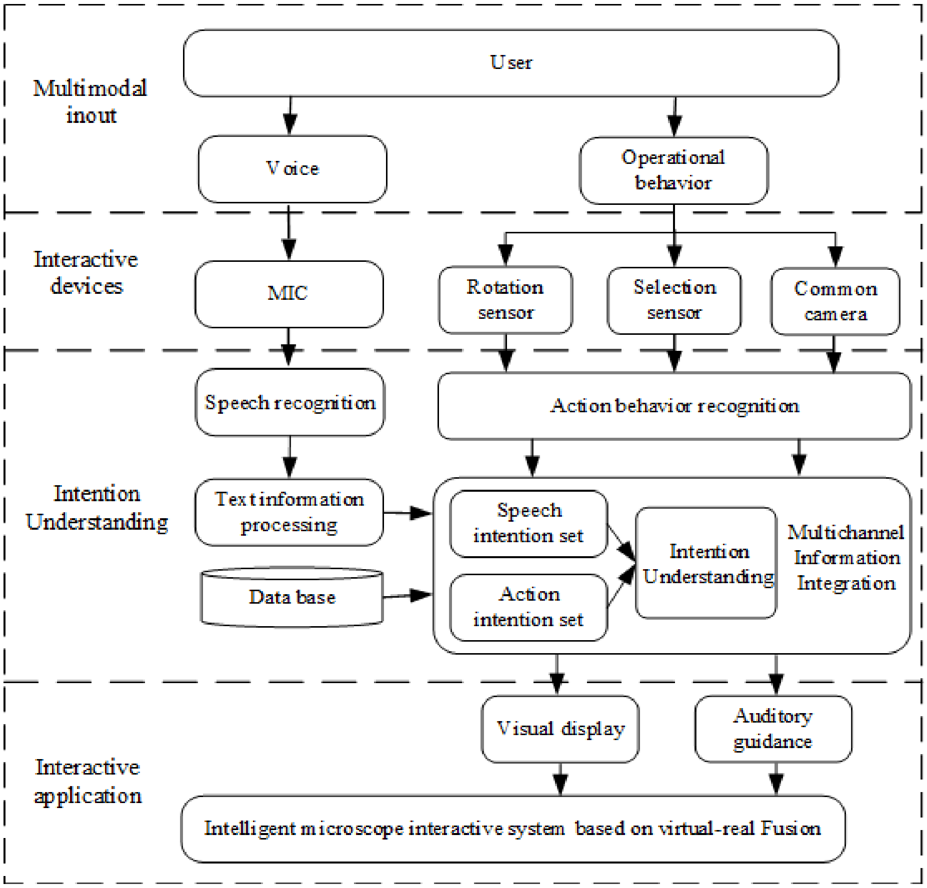

FIGURE 1. Overall framework for multimodal interaction experiments.

B. INFORMATION ACQUISITION AND PROCESSING IN DIFFERENT CHANNELS

1) VISUAL CHANNEL INFORMATION PROCESSING

Let the RGB image after the sample tag be identified as the original image and D be the set of sample images. When moving the sample label, the observed sample content changes. If the current observed image is P, the moving transformation function is $PM()$, and the newly generated image is P', then the transformation process can be expressed as follows:

$$P'(x, y) = PM(x - \Delta x, y - \Delta y). \tag{1}$$

Among them, P in D, and (x, y) is the pixel in the image. The Δx, Δy pair are the offset of the pixel points in image P of the two frames before and after imaging. The formula $PM()$ is not difficult to obtain by the microscope imaging features.

2) TACTILE CHANNEL INFORMATION PROCESSING

Adjusting the coarse quasifocus spiral or fine quasifocus spiral changes the image sharpness. It is advisable to set this adjustment change as the rotation change function $PV()$. According to the designed sensing element, the coarse pseudofocus spiral is adjusted to obtain a series of discrete values $t,t \in T\{11.12, 13, 14, 15\}$. Let S_{xy} denote a window whose center point is at (x, y) and whose size is $m \times n$, where:

$$\begin{cases} m = 6t - 51 \\ n = 2t - 9 \end{cases} \tag{2}$$

Then, the newly generated image P' can be obtained according to the rotation change function.

$$\begin{aligned} P'(x, y) &= PV(P(x, y), S_{xy}) \\ &= \frac{1}{mn} \sum\nolimits_{(x,y)\in S_{xy}} P(x, y) \end{aligned} \tag{3}$$

Among these parameters, $P(x, y)$ is the image observed under the current window.

We adjust the fine adjustment and obtain a set of discrete values $s,s \in S\{1, 2, 3, 4, 5, 6\}$; Let S_{xy} denote a window whose center point is at (x, y) and whose size is $m \times n$, where:

$$\begin{cases} m = 6s - 5 \\ n = 4s - 3 \end{cases} \tag{4}$$

For the same reason, $P(x, y)$ and S_{xy} are brought into formula (3) to obtain the newly generated image P'.

3) DUAL CHANNEL INFORMATION INTEGRATION

According to our operating experience, it is possible to eliminate the operation of adjusting both coarse and fine

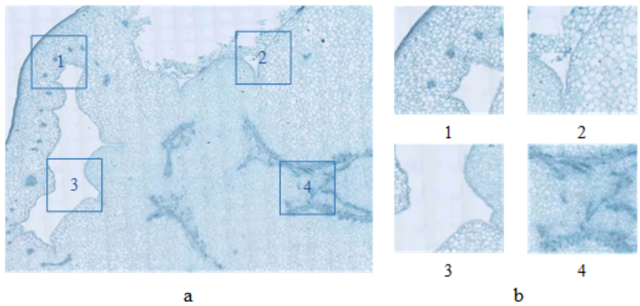

FIGURE 2. MCST strategy.

focusing helix and moving sample. Let the multichannel integration function be $Muf()$, the image before adjustment be P, the movement transformation function be $PM()$, and the rotation transformation function be $PV()$. Therefore, the multichannel integration function can be expressed as:

$$Muf(P) = \alpha PM(P) + (1 - \alpha)PV(P) \tag{5}$$

Among these parameters, $\alpha(\alpha = 0, 1)$ is the selection parameter which can be changed by the selection sensor. When an adjustment is completed, $P'' = Muf(P')$ can continue to be adjusted, where P' is the current observed image.

C. MULTICHANNEL INFORMATION INTEGRATION

1) MULTICHANNEL INFORMATION INTEGRATION STRATEGY

In the entire interactive system, it is necessary to integrate the information of three channels to complete the intelligent human-computer interaction work. In the whole management process, a multichannel-based state migration strategy (MCST) is proposed, and the information of different channels is taken as input. The system's adjustment and feedback process is used as the state. Different trigger conditions cause migration changes between different states, thereby integrating information and producing reasonable feedback. The MCST strategy is as follows.

The circle indicates the state of the current execution; the directed edge points may be converted to the state, and the directed edge is accompanied by the conditions that need to be met for the transition. Inputs in the integration strategy include the image information P_0,P_1, haptic information α, t (obtained by the sensing element), and voice. The output content is P_1,P_2,P_3 and voice prompts. Among these parameters, P_0 is a sample label map, P_1 is a marker map for controlling sample movement, P_1,P_2 and P_3 are observed sample images. The α is the state conversion parameter, and s, t are the sharpness adjustment parameters. During execution, the system status changes based on different user behaviors. For example, after the sample tag P_0 is successfully identified, the sample P after the blurring process is displayed, and the user can select the moving sample for observation or can choose to adjust the current sample clearly, such as $\alpha = 0$, and the system enters the sample moving state. The camera detects the sample motion, and the system then calculates the offset ΔX and ΔY in real time and displays the moved sample P_2. When the user moves the sample constantly, the system remains in the "picture move" state. At this point, the user can observe the sample movement effect and find the area of interest. In addition, the user can set the state conversion parameter $\alpha = 0$ to make the system transition to the "recognition adjustment" state. C is an intent predictor variable, which is not a user input but a control condition generated by the system based on the sharpness of the current image P_2. When P_2 satisfies the definition requirement, the system considers that the user has obtained the ideal sample image; that is, it is inferred that the user will continue to observe the sample image at this time. Therefore, the user is guided to save the current image for later observation. The system activates the "voice interaction" state, prompting the user to save the current image. If the user chooses to save the image, the system enters the "save" state; otherwise, it returns to the previous state. If the image is saved successfully, the system return to the image "display" state. If saving is unsuccessful, the user is prompted to voice the command again. (According to the confidence of voice recognition, we attribute unsuccessful saving to a voice input that does not meet the requirements, requiring the user to redo the voice interaction state.)

2) USER INTENT SPECULATION AND OPERATION TIPS

Users often conduct microscopy experiments with the aim to find the area of interest and observe it at an appropriate magnification. Therefore, we divide the user's intention into three categories: finding the area, adjusting the clarity and other intentions. The region searching needs to be determined according to the movement of the sample label and the combination of the "region box". The adjustment of clarity needs to be judged according to the multiple of rotating sensors and converters, and stipulates that other behaviors in the operation process are "friendly behaviors", that is, they will not have other effects on the experiment, so as to ensure that the experimental purpose can be achieved eventually. The intention of the user to find the area and the intention to adjust the definition are determined as follows.

a: LOOKING FOR AN AREA

The area box is a fixed-size display window. We select a rectangular box with a size of 200200 that can slide left and right on the original image with a resolution of 13001000. The point (x, y) at the upper left corner of the box lies in the original image. The position on the top is designated the origin. The position of the point in the upper left corner of the box on the original image is marked as the origin (x_0, y_0), and the initialization origin $x_0 = 400$, $x_0 = 400$. Using ΔX and ΔY to control the displacement of sample detection points, the effect is as follows.

Fig. 3(a) is a tomato sample image observed under a microscope. We store the image as the original image in a database file. When moving the observation sample, the area box slides on the original image, and the contents of Fig. 3(b) can be observed under an intelligent microscope. Therefore, users

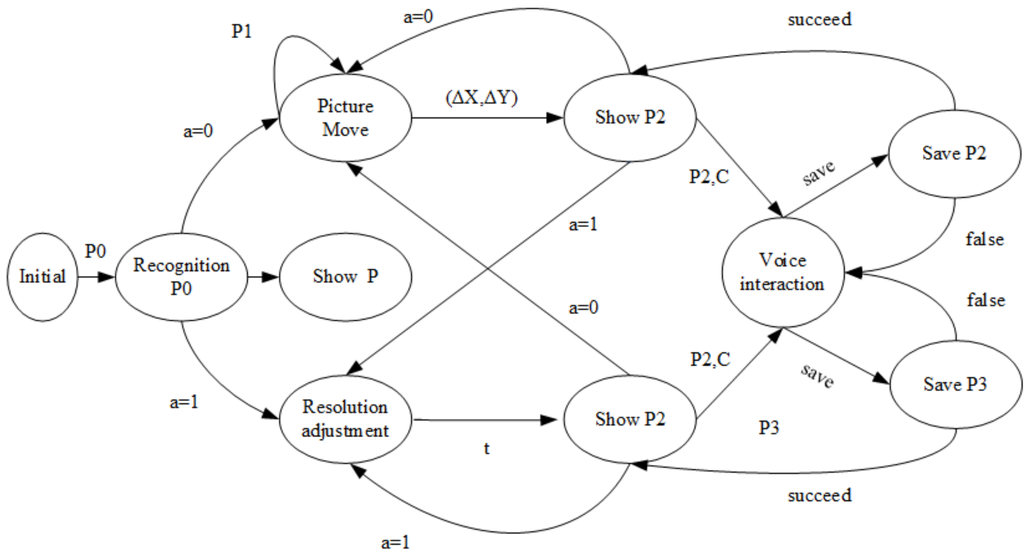

FIGURE 3. Rectangular box display.

TABLE 1. User move intent decision table.

Movement intention	Evaluation condition (Δx, Δx)
Move to the left	$\Delta x > 0$ and $-0.5\Delta x < \Delta y < 0.5\Delta x$
Move to the lower right	$\Delta x > 0$ and $-1.5\Delta x < \Delta y < -0.5\Delta x$
Move downward	$\Delta y < 0$ and $0.5\Delta y < \Delta x < -0.5\Delta y$
Move to the lower left	$\Delta y < 0$ and $1.5\Delta y < \Delta x < 0.5\Delta y$
Move to the left	$\Delta x < 0$ and $0.5\Delta x < \Delta y < -0.5\Delta x$
Move to the upper left	$\Delta x < 0$ and $-0.5\Delta x < \Delta y < -1.5\Delta x$
Move up	$\Delta y > 0$ and $-0.5\Delta y < \Delta x < 0.5\Delta y$
Move to the upper right	$\Delta y > 0$ and $0.5\Delta y < \Delta x < 1.5\Delta y$

can freely move samples to find regions of interest. When users search for regions of interest, their intention of moving can be classified into the following aspects:

Calculate the offset Δx and Δy of two consecutive frames of the sample. According to the evaluation condition of Table 1, the relative motion direction of the sample label can be inferred, and then the position of the area box on the original image can be changed so that the window can be realized on the image. The user moves the box left and right until finding the area of interest. Because the moving direction of the sample is not fixed, it is very likely that the observation window will exceed the allowable range of the sample image. Therefore, the system needs to give a certain cross-border reminder according to the user's mobile intention. The distance between the area box and the boundary in this direction is Δd, and the threshold value for cross-border reminder is D. With the movement of the area box, real-time calculation of Δd, when $\Delta d < D$, voice alerts users. For example, when the user moves the sample downward and $\Delta d < D$, the system prompts, "Move the sample upward when you are about to go beyond the area below." Other situations are similar.

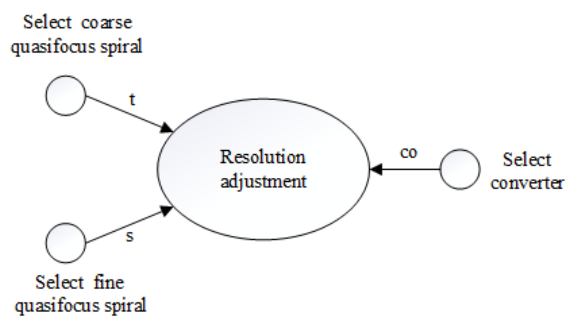

FIGURE 4. The way users adjust clarity.

b: ADJUSTING THE CLARITY

When users adjust the sharpness of observation samples, the purpose is to adjust the observed blurred samples clearly. Therefore, in the process of multi-channel information integration, it is only necessary to understand how the user adjusts the sharpness by choosing different amplification multiples of the converter, or by rotating the coarse or fine focusing helix, as shown in Fig. 4.

In the figure above, the magnification of the converter is $co, co \in \{10, 40\}$, and the magnification of the eyepiece is always 10 times. The t and s are discrete values obtained by adjusting coarse and fine focusing helix, respectively. Because the design of intelligent microscope increases the discrimination of different sensor elements. So according to the change of the current sensor value, we can know what kind of adjustment operation the user carries out. This method uses the difference of sensor values to distinguish how the user adjusts the sharpness of the sample, which reduces the difficulty of distinguishing the user's intention to a certain extent.

TABLE 2. Dividing table of sample clarity.

Sample clarity	t	s	co
Vague	$\geqslant 14$	$\geqslant 1$	10
Clear	$\leqslant 13$	$\geqslant 1$	10 or 40
The clearest	11	1	10 or 40

It is stipulated that the clarity can be graded when the fine focus screw is used to adjust the image clearly or when the coarse focus screw is used to find the outline of the sample image. Then, according to the current set of observations, we can infer the clarity of the current sample and the user's adjustments to the clarity, as shown in Table. 2.

As shown in the table above, the clarity in the adjustment process is roughly divided into three levels, which are vague, clearer and clearest. We do not have very strong evidence to prove that such a division is very reasonable, but only from the actual observation effect, according to the practice to determine the classification criteria. According to the expert system, the experimenter observes the sample under the low power mirror first and then under the high power mirror in the actual process of using the microscope. In the use of a microscope, the experimenter usually needs to rotate the coarse focusing helix first, until he sees a clearer image, and then rotates the fine focusing helix to fine-tune the observation effect. When experimenters use smart microscopes, they also need to go through appeal steps to observe clear images. When rotating the coarse and fine focusing helix of the smart microscope, data are collected through multiple channels, and according to the changes of these values, the degree of current user's image sharpness adjustment is inferred. When $t = 11$ and $s = 1$ are satisfied, the clearest observation sample can be seen. At the same time, the system infers that the user has obtained the ideal sample, and through voice, prompts the user: "Under the magnification co, you have got the clearest sample, please choose to save!". One of its purposes is to remind users that the current observation sample has been adjusted to the best state, and then continue to adjust, the image will become blurred. The other is to tell users that the system has the function of saving observation samples, users can choose to save the current observation image to share. In summary, according to the user's choice of different ways of adjusting clarity and the current degree of clarity adjustment, the system has completed the understanding of user's clarity adjustment intention and related guidance reminders.

IV. INTELLIGENT MICROSCOPE DESIGN FOR MULTIMODAL INTERACTION

A. INTELLIGENT MICROSCOPE DESIGN

The intelligent microscope replaces the mirror and stage with a cube and special treatment of the slide. A miniature camera is placed inside the cube, and the camera faces the light-passing aperture for viewing the slide. The upper surface of each slide is labeled with a unique two-dimensional code, and the lower surface is a black round surface with a red mark. The design of the structure mainly accomplishes the following two functions:

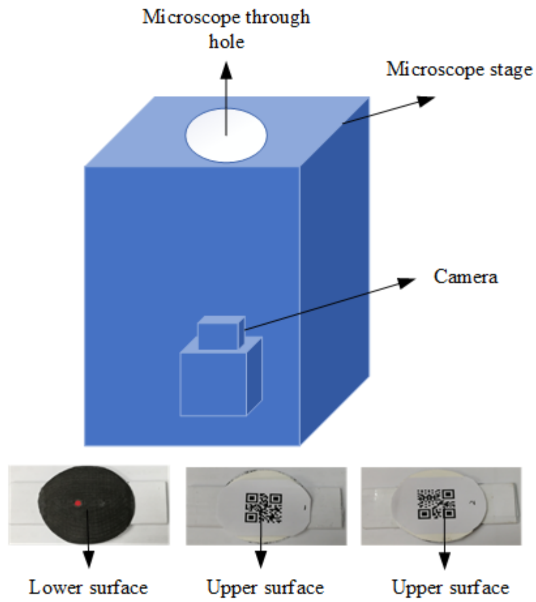

FIGURE 5. Microscope stage and slides.

1) Sample identification
   The sample recognition uses image recognition, and the upper surface of each slide has a two-dimensional code picture representing the sample; according to the recognized two-dimensional picture, the image is sampled from the database. When initializing the sample image, a very blurred sample P can be observed.
2) Sample movement detection
   Using the detection mark on the lower surface of the slide and formula (1), the movement of the sample before and after observation can be used to calculate the movement of the sample in real time, and the sample image P_2 can be observed according to the offset Δx, Δy.

During operation, the two-dimensional code of the upper surface of the slide glass is first directed to the light-passing aperture, and once the camera identifies the sample label, the lower surface of the slide glass is placed on the aperture. When the sample is moved left and right, the camera controls the sample under the microscope in the opposite direction based on the position where the red mark is detected.

As shown in Fig. 6, the coarse and fine quasi-focal helix consists of two concentric cylinders of different sizes. One end is sealed and the other end is designed with a shading rotating axis. The shading rotating axis allows only light to be emitted from a fixed angle. Six photosensitive sensors are evenly embedded in the inner cylinder of a concentric cylinder. When the shading axis is rotated, the photosensitive sensor is illuminated by light in turn. After treatment, different discrete values are obtained. According to formulas (2), (3), (4), the sharpness of sample image can be adjusted.

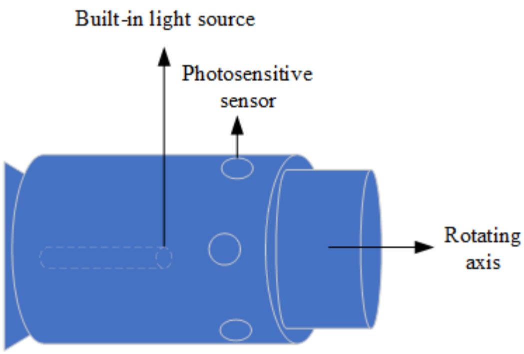

FIGURE 6. Coarse and fine focus spiral.

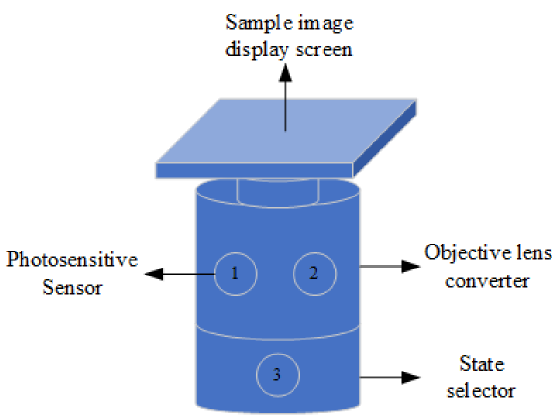

FIGURE 7. Converter prototype.

Fig. 7 shows the prototype of the converter, which includes an objective converter and a state converter. At the top is the intelligent display screen. The effect of sample adjustment is displayed on the screen in real time. Three pressure sensors are mounted on the lens barrel. Pressing sensor 1 or sensor 2, and you get different co values, representing an objective lens magnification of 10 or 40 times. Sensor 3 is a state selection sensor, which generates a selection parameter çÁ to complete the state transition.

B. NAVIGATIONAL INTERACTION PARADIGM BASED ON MULTIMODAL INTENT UNDERSTANDING

According to the structural design of the intelligent microscope and the prediction of user intention, to facilitate the user's actual operation and meet the needs of the user's intelligent interaction, a navigation interaction paradigm (guided interaction algorithm, or GI algorithm) is proposed for intelligent interaction. The algorithm is described as follows:

The navigation interaction algorithm describes the navigation guidance of the intelligent microscope to the user during the adjustment process, avoids error adjustment and prompts the user to ensure effective operation. The appeal algorithm only shows part of the navigation hints. In step 3, only four moving directions are used, namely, upper, lower, left and right. In addition, according to the direction of user movement described in Table 1, eight directions can be set. Based on

Algorithm 1 An Example for Format for & While Loop in Algorithm

Input: The vertex position (x_0, y_0) of the upper left corner of the area box; the sample movement amount Δx, Δy; the conversion adjustment value α; the coarse pseudofocus spiral rotation value t ; the fine pseudofocus spiral rotation value s ; and the objective lens magnification co;

Output: Voice prompts

1: Check whether the input value is normal,if normal then continue to execute, else re-initialize;

2: **while** The conversion adjustment value $\alpha = 0$, and s, t exist **do**

3: According to the intention of the user to adjust the definition, determine whether the pair s and t meets the condition of the clearest sample, and adjust the clear execution step 4; otherwise; continue to execute the loop or end according to the user operation;

4: Voice prompt: "At the magnification co, the clearest image is obtained; please choose to save the current image!" and input according to the user's voice input;

5: **end while**

6: **while** Conversion adjustment $\alpha = 1$,(x_0, y_0) and Δx,Δy exist and do not exceed the image boundary range **do**

7: Determining a moving direction according to the user's motion intention and calculating a distance ΔD between the rectangular box and the boundary of the direction;

8: Determining whether Δd is less than the threshold D, with $\Delta d < D$, and then executing step 10, otherwise continuing to execute the loop or ending the adjustment according to user operation;

9: Voice prompting "The region of interest will move beyond the direction boundary; please move in the opposite direction" and adjusting the image according to user operation;

10: **end while**

the appeal-based interaction paradigm, the intelligent microscope can intelligently guide and correct ineffective user behavior.

V. EXPERIMENTAL RESULTS ANALYSIS AND EFFECT

The host processor selected during the experimental operation was an Intel(R) Core(TM) i5-6500 CPU, 3.2 GHz, running on a 64-bit Win10 system, and the microscope was equipped with a smart microscope kit.

A. EXPERIMENTAL RESULTS AND VERIFICATION

Smart microscopes are different from traditional microscopes. Instead of being constructed from optical components, smart microscopes are constructed using a variety of sensors and communication module configurations. Identifying a simple customized sample with a label has the advantage of avoiding excessive student effort in sample preparation and avoiding poor performance due to improper

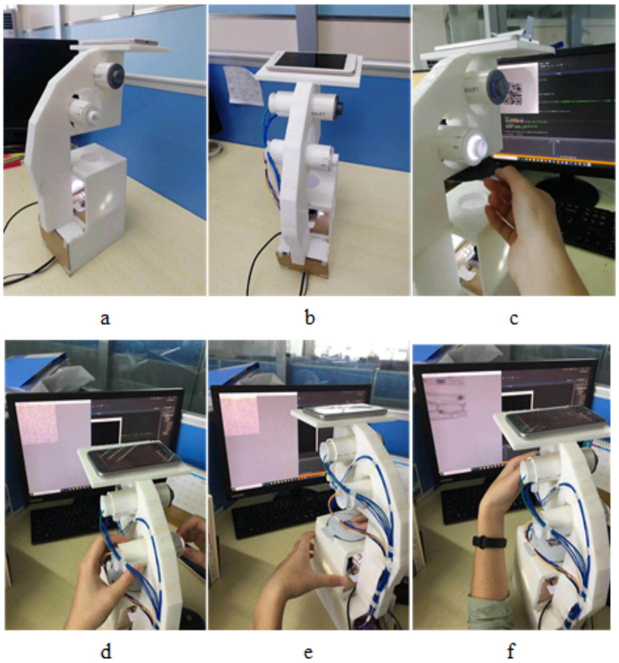

FIGURE 8. Experimental effect image display.

sample preparation. It also solves the problem that samples are difficult to obtain and cannot be reused. Of course, the downside is that this approach requires additional training in sample preparation. However, our aim is to enable students to focus more on the structure and use of the microscope and to solve the difficult problems of acquiring, saving and sharing sample images to avoid imperfect implementation and teacher difficulty in evaluating experimental learning. Microscope-supported secondary school provide superior experimental environmental support. Therefore, we believe that this treatment is more reasonable and acceptable than other approaches.

1) EXPERIMENTAL EFFECT DISPLAY

Figs. 8 and 9 are from the actual experimental operation of the user, and we have selected representative points in the experiment for illustration.

As shown in Fig. 8, the smart microscope is similar in appearance to the traditional microscope used in the secondary school teaching process and has similar functions. It includes coarse focusing helix, fine focusing helix, carrier platform, through hole and electronic display screen, etc. In Fig. 8(c), the microscope identifies the sample, and the user can observe the corresponding sample image according to different sample labels. In Fig. 8(d), the user adjusts the sample sharpness by the fine quasifocus spiral. In Fig. 8(e), the user moves the observation sample left and right to find the region of interest. In Fig. 8(f), the user selects eyepieces with different magnifications and observes that the current sample is enlarged to the corresponding magnification. Note that the user can observe the same sample image from the computer screen and the microscope display screen, which eliminates inconsistency between user operation and user observation in actual operation. With an actual microscope, if the user operates the microscope with one hand while watching the computer display, disorientation can easily occur during operation. Therefore, the microscope display has been added to solve this inconsistency problem.

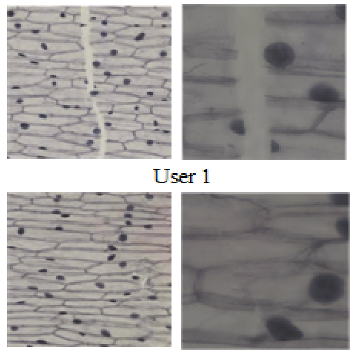

FIGURE 9. Observed images saved by different users.

The above image shows an image of an observation sample saved by two users at different magnifications. (The sample is onion skin.) The sample images observed by the different users are from different parts of the same observation sample. This aspect reflects the difference in the region of interest between different users. Furthermore, it shows that the intelligent microscope can support the user in finding the area of interest and saving the image to facilitate the sharing of observations. Finally, it helps teachers evaluate students' practical learning, which is a clear distinction from the use of traditional microscopes and some software teaching platforms.

2) VERIFICATION OF THE MCST TECHNIQUE

To verify the multichannel-based state migration strategy (MCST) proposed in this paper, in which the information of different channels is integrated and the feedback and intelligent interaction are performed in real time, the following experimental verification is designed. We organized 20 experienced operators to observe onion epidermal cells with a smart microscope, and the experimental requirements are as follows:

1) Each operator adjusts the microscope at its own normal speed, slower speed and faster speed;
2) The experiment process needs to be completed once, with no intermittent waiting at intermediate steps;
3) The sample must be adjusted to produce a clear image under the condition that the magnification of the objective lens is 10 times and 40 times;
4) After hearing the save prompt, the user engages in man-machine dialogue according to their natural reaction speed and saves the observation sample image;

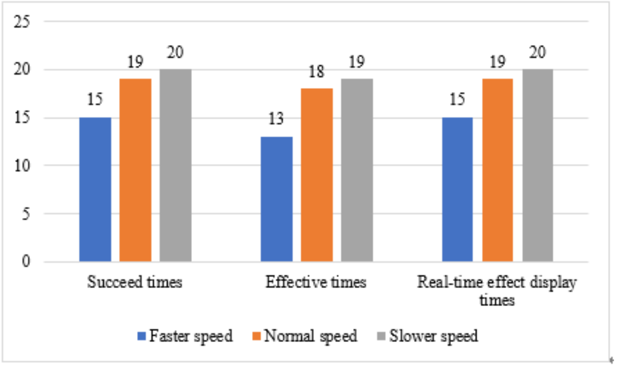

FIGURE 10. Statistical analysis of the number of successes.

5) The user performs the operation of moving the sample up, down, left, and right until the guidance prompt is heard in each direction;
6) After hearing the guidance prompt, the user acquires the correct adjustment according to their natural reaction speed.

During this operation, the recorder needs to record the number of times the experimenter has successfully completed the experiment at a normal speed, a faster speed and a slower speed. (''Success'' here refers to: the normal operation of the system, will not terminate; in three magnification can be adjusted to clear samples, including magnification of 10 times the eyepiece; after adjusting clear can hear save prompts; user voice input ''save'', the system can react; mobile samples can hear the system prompts, which corresponds to the completion of tasks 1 through 6). It is also necessary to record the effective times for 20 experimenters to complete the experiment at their normal speed, slower speed and faster speed. (The effective times here refer to: under the ''successful'' completion of the experiment, the clearest images can be saved under three enlargement preservation multiples, and the experimenters can complete the requirements at their normal speed and faster speed. 5 and 6 can successfully see the real-time effect without the number of delays.

As shown in Fig. 10, the success number of the 20 operators who completed the requests at different speeds was 54 times; the successful completion rate was 90%, the number of effective experimental operations was 50, and the effective experimental rate was 83.3%. That is, the operators not only completed the experiment but also saved the image clearly, and the feedback of the smart microscope during the experiment was provided in real time. Note that the number of effective successes is lower than the number of successful completions of the experiment. Considering the analysis of the above table and experimental process, the main reason is that on the one hand, the voice input process is delayed, and excessively fast operation causes some save operations to be delayed. On the other hand, when the sample is moved at a faster speed, moving past the border becomes more likely, causing the system to terminate execution. Since the actual experimental operation is completed at a natural speed, it is generally not completed at a relatively fast speed, so the intelligent microscope can meet the user's teaching practice requirements. It can also be obtained from the information in the above figure that 20 operators could complete the experiment at normal speed. After the clear sample observation image was adjusted, the system voice prompt was successfully heard 19 times, and the voice guidance was always successfully heard. Nineteen times corresponds to a success rate of 94%. The requirements that the navigation interaction be understood ensures effective navigation guidance to the user.

In summary, to a certain extent, it is considered that the MCST strategy and GI algorithm proposed for multichannel integration in this paper are reasonable in the design of intelligent microscopy. The former can integrate the information of different channels to understand the user's intention, and the latter can realize navigation guidance based on the user's intention to achieve the purpose of intelligent interaction.

B. COMPARATIVE EXPERIMENTS

To further test whether the smart microscope kit reached the design goal, we compared it with the Nobook's [31] virtual simulation microscope and traditional microscope in terms of the interactive intelligence, the sense of operation experience, the cognitive level of the microscope structure, the convenience of learning evaluation, the sharing of experimental results, the implementation effect and the enthusiasm of students. The seven levels of appeal are referred to as SUD_M (7 degrees of practicality of microscopy education). Finally, based on the SUD_M and NASA scores, we evaluated the advantages and disadvantages of the smart microscope interaction kit. During the experiment, 10 experienced teachers and 30 students from Zhangqiu Middle School and Qixian Middle School in Shandong Province were invited to carry out the experiment. It should be pointed out that 30 students have learned the relevant knowledge of the operation of the microscope and the steps of adjusting the microscope in class. All 10 experienced teachers can use microscopes skillfully. The purpose of this arrangement is to obtain more effective and stable experimental data, but also in line with the actual teaching arrangements. Each student operator observed human oral epithelial cells in sequence when the samples were ready. During the test period, the total time required for each experimenter to perform three observations on different instruments and the final SUD_M and NASA evaluation scores were recorded. The SUD_M scoring method uses a similar 5-point scale scoring criteria as NASA. Each index is divided into 5 grades, but the grades are different. Taking interactive intelligence as an example: 0 ∼ 1 points means that the operation intelligence is very low, 1 ∼ 2 points means the operation intelligence is low, 2 ∼ 3 points means the operation intelligence is moderate, 3 ∼ 4 points means the operation intelligence is high, and 4 ∼ 5 points means the operation intelligence is very high.

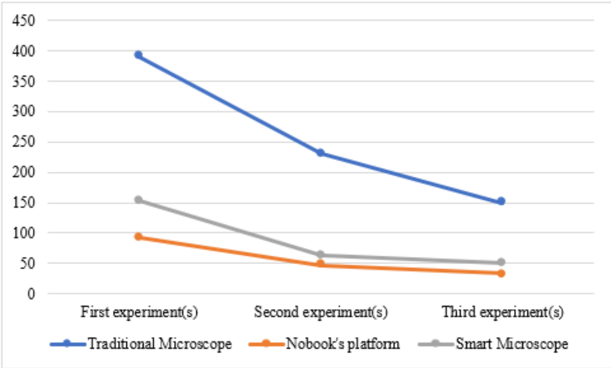

FIGURE 11. Time required to complete the experiment.

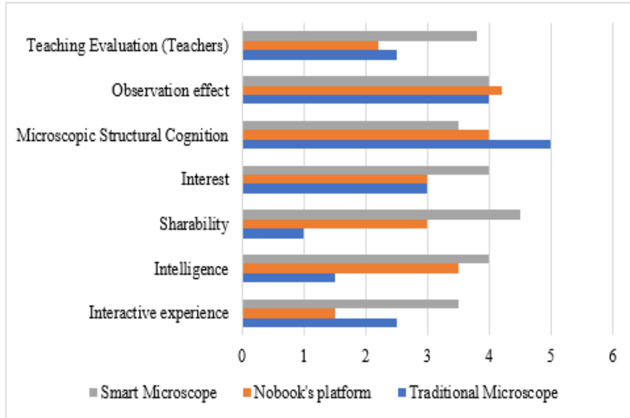

FIGURE 12. SUD_M evaluation.

The operation experience is also divided into 5 levels, from very poor to very good.

It was required that the 10 experienced teachers and 30 students complete 3 experiments on different platforms respectively. In each experiment, the operator needs to adjust the image clearly under the low and high power mirrors. To maintain fairness of comparison, the samples required for traditional microscope observation were already prepared in the experiment, and the operator needed only to observe and adjust without considering the task of sample preparation. During the test period, we recorded the time consumed by the experimenter in each experiment. We also calculated the average time spent by each of the 40 users on each experiment and organized them into a line chart, as shown in the image above. The results show that the Nobook's virtual microscope are the fastest and most convenient in the experimental adjustment process. The intelligent microscope comes in second. The traditional microscope adjustment takes the longest time. Its time cost is approximately 3 times that of the second place and 7 times that of the first place. Obviously, the Nobook's virtual microscope have outstanding advantages in terms of ease of use and speed of adjustment, and the intelligent microscope also has great advantages. Furthermore, as the number of experiments increases and the user experience gradually accumulates, the time taken to adjust the microscope to observe the sample is significantly shortened.

Fig. 12 shows the recorded experimental scores of the 10 secondary schools teachers and 30 secondary schools students. First, the teaching evaluation refers to the teacher's evaluation of the three experimental methods for experimental teaching. The data show that the intelligent microscope is more conducive to teachers completing the teaching evaluation because the results of the intelligent microscope can be shared and the practice process is simple and clear; in addition, it is convenient for the teacher to guide the evaluation. In terms of observation, the operators generally reported that the observation results of the three experimental platforms were very satisfactory, and clear samples could be observed in all cases. However, it was necessary to explain that the sample of traditional microscope is the high-definition sample prepared by the organizer of the experiment. This sample has good transparency, no bubble interference, no stain effect, and is superior to the temporary sample made by the experimenter himself in all aspects. At the cognitive level of the microscope structure, the intelligent microscope scores lower than the traditional microscope and Nobook's virtual microscope, because the traditional microscope and Nobook's virtual microscope enable students to accurately recognize and observe the microscope structure, including each component structure. The smart microscope scores are slightly lower than the others because this tool retains only the most important properties of the microscope and integrates or ignores other properties. In terms of intelligence, fun, and sharing, most students reported that smart microscopes can stimulate their interest, combined with intelligent interaction and sharing of observation results, making the cognitive process of microscopy learning relatively fun. In the sense of interactive experience, the intelligent microscope also has certain advantages. The reason why the traditional microscope and the Nobook's virtual microscope produce a poor interactive experience is that the former can easily lead to eye fatigue during use, and the latter offers no actual interactive experience. That interface can be operated only by the mouse, lacking realistic details of operation. In summary, from the perspective of students, although the smart microscope allows certain deficiencies in the familiarity with and cognition of the microscope structure, because of its intelligent interaction, shared design, good observation effect and good interactive experience, it is often more stimulating to students' interest in learning and is more popular among students than the other methods. From the teacher's point of view, the omission of structural components in the intelligent microscope may affect certain teaching designs but will benefit learning evaluation from other aspects.

Then, we interviewed the appellant experimenters about the introduction of intelligent microscopy in the experimental teaching process. The statistics are as follows.

The above figure shows that most students enjoyed using the smart microscope. Most teachers also agreed to introduce smart microscopes into the experimental teaching process. Two of them did not approve of the introduction of smart

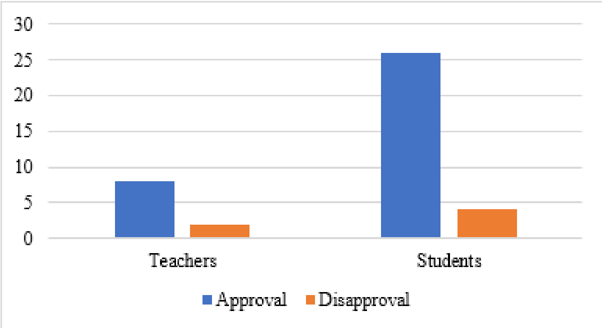

FIGURE 13. Teaching process introducing intelligent microscope support.

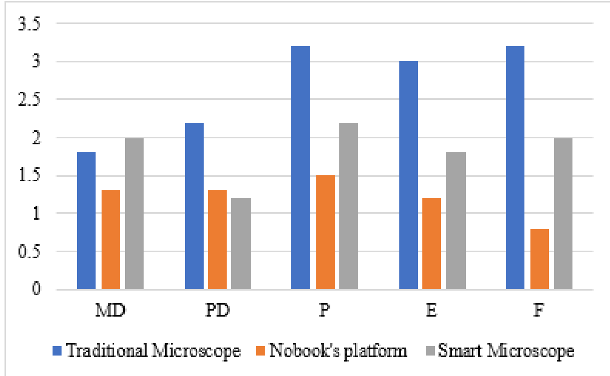

FIGURE 14. NASA user evaluation.

microscopes into teaching, however. One opined that the introduction of smart microscopes may bring other adverse effects, and another suggested that the current smart microscope function needs to be further improved and should replicate more operational aspects of traditional microscopes.

In summary, we believe that the design of the intelligent microscope, while retaining the traditional microscope contact operation experience and the recognition of the important structure of the microscope, enables the microscope to provide more powerful interactive intelligence, which is beneficial. Teachers' evaluation of teaching experiments can better stimulate students' enthusiasm for learning. In addition, the proposed tool solves the problems that sample images are difficult to acquire, save and share and that the implementation status is not ideal. Therefore, the design of the intelligent microscope interaction kit meets the intended design purpose and can be used in certain secondary school teaching experiments.

C. USER EVALUATION

To test whether the intelligent microscope meets the design requirements and to evaluate its advantages and disadvantages, the user evaluation on seven levels regarding appeal is given in Fig. 12. In addition, the NASA evaluation comparison is given for the cognitive load of the user during the experiment. The user evaluation indicators are divided into mental demand (MD), physical demand (PD), operational performance (performance, P), effort (E) and frustration (F). Among them, the mental force requirement describes the user's operational memory load, the physical requirement describes the degree of user operational difficulty, the operational requirement describes the smoothness of the user operational performance (the smoother the operation process is, the smaller the user's operation burden), the effort level describes the user's effort during the operation and whether it feels relaxed, and the degree of frustration describes the degree of negative user experience during the operation. The NASA evaluation index uses a 5-point scale. Each indicator is divided into 5 levels: 0 to 1 indicates that the cognitive burden is small, 1 to 2 indicates that the cognitive burden is relatively small, 2 to 3 indicates that the cognitive burden is moderate, 3 to 4 indicates that the cognitive burden is relatively large, and 4 to 5 indicates that the cognitive burden is large. Fig. 14 shows that the intelligent microscope constructed in this paper has a lower cognitive load than the traditional microscope and does not require intensive interaction tasks by the user; in addition, the user evaluations are high.

VI. SUMMARY

In this paper, in the context of the current teaching process of experimental microscopy in secondary school, there are widespread problems in that microscopy samples are difficult to produce, preserve and share, the implementation status is not ideal, and the teacher cannot readily evaluate the extend of learning during experiments. A smart microscope physical interaction suite for secondary school biology experiments was constructed. A novel multichannel information integration strategy based on visual, auditory and tactile information was proposed to manage the information input of different channels of users, understand the user's operational intentions and organize reasonable interaction behaviors. In addition, a navigational interaction paradigm based on multimodal intent understanding is proposed. On the basis of this paradigm, a means to alert users of ineffective operation behavior and to guide necessary operations is completed, and finally, intelligent interaction and intelligent experimental teaching are realized. The main contributions of the intelligent microscope designed in this paper are as follows:

1) It solves some of the bottleneck problems and related constraints that have been difficult to solve in the current setting of secondary school experimental microscopy teaching and imbues experimental microscopy methods with typical features such as intelligence and interactivity;
2) Using multi-channel fusion technology and intelligent interaction breaks through some limitations of traditional microscopy and virtual microscopy, increases students'learning fun, and helps teachers and students to interact in teaching.
3) Through physical operation, the operating experience under real microscopy conditions can be realized,

and relevant experimental skills can be mastered.The results have been well received by users in the evaluation of effects.

Nevertheless, there are some areas for improvement in smart microscopes, while ignoring some of the operational details of traditional microscopes. Some examples include the lack of operation of the light and the lack of adjustment of the mirror to change the intensity of the light. To some extent, this makes the operation of the microscope simpler. On the other hand, in terms of information enhancement, we can make further exploration.

REFERENCES

[1] U. Catalyurek, C. Chang, T. Kurc, A. Sussman, J. Saltz, and M. D. Beynon, ''The virtual microscope,'' *IEEE Trans. Inf. Technol. Biomed.*, vol. 7, no. 4, pp. 230–248, Dec. 2004.

[2] G. Corredor, E. Romero, and M. Iregui, ''An adaptable navigation strategy for Virtual Microscopy from mobile platforms,'' *J. Biomed. Inform.*, vol. 54, pp. 39–49, Apr. 2015.

[3] T. G. Papathomas *et al.*, ''SDHB/SDHA immunohistochemistry in pheochromocytomas and paragangliomas: A multicenter interobserver variation analysis using virtual microscopy: A multinational study of the European network for the study of adrenal tumors (ENS@T),'' *Mod. Pathol.*, vol. 28, no. 6, p. 807, 2015.

[4] L. M. J. Lee, H. M. Goldman, and M. Hortsch, ''The virtual microscopy database—Sharing digital microscope images for research and education,'' *Anatomical Sci. Educ.*, vol. 5, no. 11, pp. 510–515, 2018.

[5] R. Mirko, K. Goran, S. Damir, and V. Antonio, ''The use of microscope in school biology teaching,'' in *Proc. 13th Int. Multinational Congr. Microscopy*, Rovinj, Hrvatskoj, 2017, pp. 24–29.

[6] G. Y. Zeng and L. P. Wang, ''Teaching reflection on the use of microscope,'' *Exp. Teach. App.*, vol. 27, no. 1, pp. 35–36, 2011.

[7] H. Tang, ''Make up for the shortcomings of traditional high school biology experiment teaching by using micro-lessons and digital micro scopes: A case study of observation of mitosis of apical meristematic cells,'' *Exp. Equip. Primary School*, vol. 29, no. 1, pp. 48–49, 2019.

[8] L. Dinescu, C. Miron, E. S. Barna, and M. Dinica, ''The approach of teaching and learning scanning electron microscope in high school using virtual experiments,'' *Romanian Rep. Phys.*, vol. 65, no. 2, pp. 578–590, 2013.

[9] J. Wang, ''Research on the application of virtual simulation experiment in physics experiment teaching of senior high school,'' M.S. thesis, Dept. Subject Educ. Eng., Liaoning Normal Univ., Dalian, China, 2018.

[10] R. P. Cohen and D. R. McGee, ''Tangible multimodal interfaces for safety-critical applications,'' *Commun. ACM*, vol. 47, no. 1, pp. 41–46, Jan. 2004.

[11] I. P. Ktistakis and N. Bourbakis, ''A multimodal human-machine interaction scheme for an intelligent robotic nurse,'' in *Proc. IEEE 30th Int. Conf. Tools Artif. Intell.*, vol. 1, Nov. 2018, pp. 749–756.

[12] H. Gunes and M. Piccardi, ''Affect recognition from face and body: Early fusion vs. late fusion,'' in *Proc. IEEE Int. Conf. Syst.*, Waikoloa, HI, USA, vol. 3, Oct. 2006, pp. 3437–3443.

[13] M. H. Yang and J. H. Tao, ''Nature multimodal human-computer-interaction dialog system,'' *Comput. Sci.*, vol. 41, no. 10, pp. 12–18, Oct. 2014.

[14] M. H. Yang, J. Tao, L. Chao, H. Li, D. Zhang, H. Che, T. Gao, and B. Liu, ''User behavior fusion in dialog management with multi-modal history cues,'' *Multimedia Tools Appl.*, vol. 74, no. 22, pp. 10025–10051, 2015.

[15] I. Dialsingh, ''Risk assessment and decision analysis with Bayesian networks,'' *J. Appl. Statist.*, vol. 41, no. 4, p. 910, 2013.

[16] C. Pradalier, F. Colas, and P. Bessiere, ''Expressing Bayesian fusion as a product of distributions: Applications in robotics,'' in *Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst.*, Las Vegas, NV, USA, vol. 3, Oct. 2003, pp. 27–31.

[17] A. Savran, A. Cao, H. Nenkova, and A. Verma, ''Temporal Bayesian fusion for affect sensing: Combining video, audio, and lexical modalities,'' *IEEE Trans. Cybern.*, vol. 45, no. 9, pp. 1927–1941, Sep. 2015.

[18] G. Li and W. X. Lin, ''An adaptive importance sampling algorithm for Bayesian inversion with multimodal distributions,'' *J. Comput. Phys.*, vol. 294, pp. 173–190, Aug. 2015.

[19] J. McIntosh, A. Marzo, M. Fraser, and C. Phillips, ''EchoFlex: Hand gesture recognition using ultrasound imaging,'' in *Proc. ACM CHI Conf. Human Factors Comput. Syst.*, Denver, CO, USA, Jun. 2017, pp. 1923–1934.

[20] Y. Sugano, X. Zhang, and A. Bulling, ''AggreGaze: Collective estimation of audience attention on public displays,'' in *Proc. 29th Int. Annu. Symp. User Interface Softw. Technol.*, Tokyo, Japan, Oct. 2016, pp. 821–831.

[21] M. L. Seltzer and J. Droppo, ''Multi-task learning in deep neural networks for improved phoneme recognition,'' in *Proc. IEEE Int. Conf. Acoust., Speech Signal Process.*, Santiago, Chile, May 2013, pp. 6965–6969.

[22] E. Tzeng, J. Hoffman, T. Darrell, and K. Saenko, ''Simultaneous deep transfer across domains and tasks,'' in *Proc. 19th Int. Conf. Comput. Vis. (ICCV)*, Santiago, Chile, Dec. 2015, pp. 4068–4076.

[23] D. Yoon, K. Hinckley, F. Guimbretière, P. Irani, M. Pahud, M. Gavriliu, and H. Benko, ''Sensing tablet grasp + micro-mobility for active reading,'' in *Proc. 28th Int. Annu. ACM Symp. User Interface Softw. Technol.*, Charlotte, NC, USA, Nov. 2015, pp. 477–487.

[24] T. Hagiya, T. Yazaki, and T. Horiuchi, ''Typing tutor: Individualized tutoring in text entry for older adults based on input stumble detection,'' in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, San Jose, CA, USA, vol. 59, May 2016, pp. 733–744.

[25] B. M. Lake, R. Salakhutdinov, and J. B. Tenenbaum, ''Human-level concept learning through probabilistic program induction,'' *Science*, vol. 350, no. 6266, pp. 1332–1338, 2015.

[26] J. Wu, J. Cheng, C. Zhao, and H. Lu, ''Fusing multi-modal features for gesture recognition,'' in *Proc. ACM Int. Conf. Multimodal Interact.*, Sydney, NSW, Australia, Dec. 2013, pp. 453–460.

[27] H. Li, P. Zhang, S. Al Moubayed, S. N. Patel, and A. P. Sample, ''ID-Match: A hybrid computer vision and RFID system for recognizing individuals in groups,'' in *Proc. 16th Int. ACM Int. Conf. Multimodal Interaction.*, San Jose, CA, USA, May 2016, pp. 4933–4944.

[28] A. L. Eberle, S. Mikula, R. Schalek, J. Lichtman, M. L. K. Tate, and D. Zeidler, ''High-resolution, high-throughput imaging with a multibeam scanning electron microscope,'' *J. Microscopy*, vol. 259, no. 2, pp. 114–120, 2015.

[29] J. A. Derose and M. Doppler, ''Guidelines for understanding magnification in the modern digital microscope era,'' *Microscopy Today*, vol. 26, no. 4, pp. 20–33, 2018.

[30] Y. LeCun, Y. Bengio, and G. Hinton, ''Deep learning,'' *Nature*, vol. 521, no. 7553, pp. 436–444, 2015.

[31] C.-C. Chiu, T. N. Sainath, Y. Wu, R. Prabhavalkar, P. Nguyen, Z. Chen, A. Kannan, R. J. Weiss, K. Rao, E. Gonina, N. Jaitly, B. Li, J. Chorowski, and M. Bacchiani, ''State-of-the-art speech recognition with sequence-to-sequence Models,'' in *Proc. IEEE Int. Conf. Acoust., Speech Signal Process.*, Apr. 2018, pp. 4774–4778.

[32] K. He, J. Sun, X. Zhang, and S. Ren, ''Delving deep into rectifiers: Surpassing human-level performance on imagenet classification,'' in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (ICCV)*, Dec. 2015, pp. 1026–1034.

[33] F. Yang, W. Choi, and Y. Lin, ''Exploit all the layers: Fast and accurate CNN object detector with scale dependent pooling and cascaded rejection classifiers,'' in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR)*, Las Vegas, NV, USA, Jun. 2016, pp. 2129–2137.

[34] L. Lu, F. Tian, and G. Z. Dai, ''Multichannel cognitive and interaction models fusing touch, audio and vision,'' *J. Comput.-Aided Des. Comput. Graph.*, vol. 26, no. 4, pp. 654–661, Apr. 2014.

[35] P. McGuire, J. Fritsch, F. Rothling, G. A. Fink, S. Wachsmuth, G. Sagerer, H. Ritter, and J. J. Steil, ''Multi-modal human-machine communication for instructing robot grasping tasks,'' in *Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst.*, Lausanne, Switzerland, Sep./Oct. 2002, pp. 1082–1088.

KANG WANG was born in Zoucheng, Shandong, China, in 1993. He is currently pursuing the bachelor's degree in information science and engineering with the University of Jinan. His research interests include human hand recognition and interaction, virtual reality, and multimodal interaction.

ZHIQUAN FENG received the master's degree from Northwestern Polytechnical University, China, in 1995, and the Ph.D. degree from the Computer Science and Engineering Department, Shandong University, in 2006. He is currently a Professor with the School of Information Science and Engineering, University of Jinan. He has published more than 50 articles on international journals, national journals, and conferences in recent years. His research interests include human hand tracking/recognition/interaction, virtual reality, human–computer interaction, and image processing.

JIAN LI was born in Linfen, Shanxi, China, in 1993, He is currently pursuing the bachelor's degree in information science and engineering with the University of Jinan. His research interests include human hand recognition and interaction, virtual reality, and multimodal interaction.

RUI HAN is currently pursuing the master's degree with the School of Information Science and Engineering, University of Jinan. Her research interests include human–computer interaction and virtual reality.