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Human-Ocular-Physiological-Characteristics-Based Adaptive Console Design

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ABSTRACT A console is an important platform for controlling indoor operations and displaying information. It is an important device for human-computer interactions. Whether an operator is comfortable using a console is an important issue of concern in industry. However, previous works have focused only on the joint angle and muscle fatigue of the console user, with few works focusing on the eye comfort of users. In this paper, we propose a console design method based on the physical comfort of the human eye to allow consoles to satisfy the needs of a user regarding the joint angle and muscle comfort and to reduce the physiological fatigue of a user's eyes, thereby improving the operator's cognitive efficiency and accuracy. In addition, a software and hardware collaboration platform is used to effectively improve the stability and accuracy of the proposed method. We also propose a method for evaluating the human eye comfort of console users based on a dual-channel objective visual quality analysis system. To the best of our knowledge, this is the first work to propose an evaluation metric for determining the comfort of the human eye afforded by a console, and experiments in the real world verify the effectiveness of this metric. Through this evaluation method, a console designed by using the console optimization method proposed herein is compared with a console designed according to the previous console design method. The results prove that our proposed method can effectively improve human eye comfort when using a console.

INDEX TERMS Console, optimal design, comfort evaluation, visual quality evaluation.

I. INTRODUCTION

The console is an important platform for controlling indoor operations and displaying information. It is an important device for human-computer interactions [1]. An operator obtains the status, load, image and other information of a device through its corresponding console. After analysis and judgement, a command or task instruction can be sent to the operating device through its console. The console is an important carrier for human-machine information acquisition, information processing, and information output. Whether the soft and hard interface design conforms to human cognition and operation rules will directly affect the operator's work efficiency and comfort. In summary, the evaluation and research of various equipment consoles from the perspective of ergonomics has become a popular topic.

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Oakman *et al.* [2] proposed a practical guide for submarine console design through a systematic literature review, related standard extraction, human body data measurements, and core user research. Lingchen *et al.* [3] used the ergonomics module of the CATIA software to simulate an occupant's posture and used the ergonomics module of the CATIA software to simulate the space, visual field of view and upper limb comfort. Then, the authors evaluated and combined the results with human-machine theory to propose strategies. Shiqi and Yinhua [4] analysed the operation console and working area of the human and packaging machine in the production of sanitary scent packaging and optimized the design of the operation area to reduce operator fatigue and improve efficiency.

Combined with the above research, the current research on various consoles is based on a literature review, theoretical knowledge and standards, computer-aided design techniques, multi-variable optimization algorithms, sensible intention methods and other methods to design the basic size, structure and form of the console, device layout, device operation comfort, colour and shape design, etc. Furthermore, the proposed optimization of the design direction includes an emphasis on the influence of the console on the joint angle and muscle fatigue for operator information acquisition. Because relatively little research on cognitive orientation exists, this study proposes a console hardware optimization design method that can adapt to physiological characteristics from the perspective of the human eye physiological characteristics, combined with human eye features, eye points, line of sight, and other constraints. It establishes the matching console display position and a controller area optimal design strategy to effectively improve the operator's cognitive efficiency and accuracy.

The visual channel is the main way for people to obtain information. In the process of obtaining external information, light passes through the pupil, lens and vitreous to the retina. The cone cells and rod cells receive, process and transform this light into electrical signals and then output and transmit it to the visual cortex of the brain, where an effective visual signal is formed [5]. Studies have shown that the illumination, distribution and use of stroboscopic light will directly affect the capture of information by the human eye. The minimum resolution of the human eye for 5000 nm yellow-green light is 1 percent. When the width exceeds 1 percent, it is difficult to identify the target against a background, as a type of fusion occurs between the two. In a well-lit environment, the resolution of the human eye is roughly 3 percent. Kong *et al.* [6] studied the effects of age, line of sight, display type, font, colour contrast and other factors on the readability of Korean characters. Alhaag and Ramadan [7] used electromyography to study the effects of the pattern type, visual distance and observation time on visual fatigue. At present, the evaluation methods for visual comfort mainly include evaluating brain waves, the flash fusion threshold, the blink frequency and the pupil diameter. The brain-wave test is complicated, the test time is long, and there are certain problems in terms of the accuracy and reproducibility [8]. There are differences between test results for the same sample at different times in the flash fusion method. The stability of the same sample is debatable [9]. The blink frequency and pupil diameter can be tested and acquired by an ocular device. The process is complicated and lacks an effective benchmark.

In this paper, we propose a console design method to allow the console to meet a user's needs regarding the joint angle and muscle comfort and to reduce the physiological fatigue of the user's eyes, thereby improving the operator's cognitive efficiency and accuracy. Previous papers focused on the joint angle and muscle fatigue of the console, while less work has focused on the distance between the user and the console screen. The contributions of this paper can be summarized as follows:

- We propose a console design method to allow a console to meet a user's needs regarding the joint angle and muscle comfort and to reduce the physiological fatigue of the user's eyes, thereby improving the operator's cognitive efficiency and accuracy;
- We propose a software and hardware collaboration platform that can effectively improve the stability and accuracy of the proposed method;
- We propose an evaluation metric for determining the comfort of the human eye when viewing a console, and experiments conducted in the real world verify the effectiveness of the evaluation metric;
- These real-world experimental results demonstrate the effectiveness of our proposed method.

The remainder of this paper is organized as follows. Section 2 introduces the general architecture of the adaptive console design platform. Section 3 introduces an instance of our adaptive console design platform that allows the console to satisfy a user's needs with regard to the joint angle and muscle comfort and to reduce the physiological fatigue of the user's eyes. In section 4, we propose an evaluation metric for determining the comfort level of the human eye when viewing a console, with experiments carried out in the real world verifying the effectiveness of our proposed evaluation metric and method. Section 5 concludes this work.

II. BACKGROUND AND LITERATURE REVIEW

A. LITERATURE REVIEW

The current research on various consoles is based on a literature review, theoretical knowledge and standards, computer-aided design techniques, multi-variable optimization algorithms, sensible intention methods and other methods used to design the basic size, structure and form of a console, the device layout, the device operation comfort, the colour and shape. Ji Lijing and Mingxi [1] combined ergonomics theory and computer-aided design technology to propose a method for the size design of a vehicle console display control device. The effectiveness of the method was verified by an example of a man-machine optimization design. To some extent, the problem of the unreasonable layout of the display and control device of the vehicle console was solved, and the fatigue and operation error rate of the operator were reduced. Wei Yongquan and Wei [10] used the hierarchical connection analysis method to classify multiple display control devices with the frequency of use as the calculation variable for the double-decker driver's console layout problem and output the classification process and results. The clustering analysis results were prioritized. Based on this, combined with human factors, design rules and device layout rules, the console operation field and the field of view were analysed and verified to provide support for optimization design. Jiang Liangkui [11] applied the computer-based three-dimensional human-machine design software known as CATIA to evaluate the spatial layout of a subway train bridge, including the pedal height, leg activity space, signal field of view, emergency brake lever operation comfort, etc. Compared with the experimental results, there is consistency between the two. Zhongjing and Hui *et al.* [12]

studied and proposed a selection method for the structure and form of a weapon launching system from the perspective of ergonomics, along with a method for determining the size and colour design, which makes a console more convenient, efficient and user-friendly. Huang Yulong and Yanxi [13] proposed a method for optimizing the console layout based on the layout design principle and human factor analysis of a UAV console. The rationality and effectiveness of the optimization method were verified by an example. From the perspective of emotional intention and ergonomics, Huai and Wei [14] researched and optimized the shape and operational comfort of a submarine console to offer a better operational experience to submarine sailors. Huai and Peiguo [15] analysed the ergonomics research methods for the existing complex weapon equipment consoles and used the sample survey method to study the colour, shape and functional area arrangement of a submarine console, obtaining the optimal design strategy. Fan Wen and Wenjun [16] proposed an ant colony algorithm that is in agreement with human-machine characteristics for the main console man-machine layout optimization problem. The layout optimization of the main console of a manned submersible was used as an example to verify the effectiveness of the algorithm. A layout design that conforms to human-machine constraints improves operator comfort. Oakman *et al.* [2] proposed a practical guide for submarine console design through a systematic literature review, related standard extraction, human body data measurements, and core user research. Lingchen *et al.* [3] used the ergonomics module of the CATIA software to simulate an occupant's posture and used the ergonomics module of the CATIA software to simulate the space, visual field of view and upper limb comfort. They evaluated and combined the results with human-machine theory to propose strategies. Shiqi and Yinhua [4] analysed the operation console and working area of the human and packaging machine in the production of sanitary scent packaging and optimized the design of the operation area to reduce operator fatigue and improve efficiency.

B. DETERMINATION OF HUMAN VISUAL DISTANCE

The minimum resolution of the human eye for 5,000 nanometre yellow-green light is 1 arcminute [17]. When the width exceeds 1 arcminute, the object and background will merge together. In a general light-filled environment, the resolution of the human eye is 3 arcminute [18]. Thus, in the observation of a display screen, the distance between a person and the display screen is the visual distance h, and the minimum distance between a person and the display screen h can be expressed as the arc length a between two points.

$$a = \frac{\mathrm{h} \times \frac{6\pi}{360}}{60} = \frac{\pi \mathrm{h}}{3600} \tag{1}$$

For commonly used screens, there are 16:9 and 4:3 screen sizes. The visual distance a_1 required for screens with different sizes (expressed in diagonal size x inches) and different resolutions B can be expressed as follows:

$$\mathbf{a}_1 = \frac{3600 * 25.4\, x}{nb\pi} = \frac{91440\mathrm{x}}{nb\pi} \tag{2}$$

In the screen size calculation, because the diagonal size (inch) is used as a variable, the height of the screen increases linearly with the diagonal length. x is the screen diagonal length, and h is the screen height; thus, $x = h * 2.04$ for the 16:9 display and $x = h * 1.667$ for the 4:3 display. Therefore, in the upper variable, $n = 2.04$ in the 16:9 display and $n = 1.667$ in the 4:3 display.

The common 1280*720 and 1920*1080 resolutions of 16:9 screens are used in equation 2 to calculate the relationship between screen size and visual distance under different resolution conditions, as shown in Figure 1.

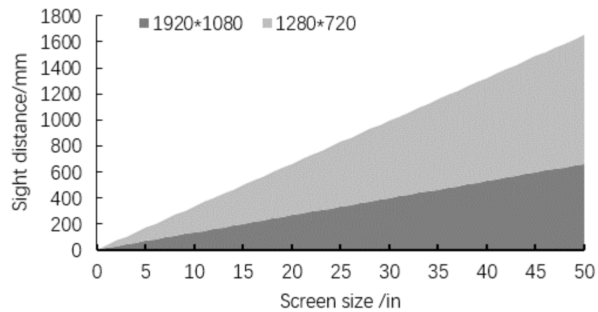


FIGURE 1. 16:9 screen resolutions and size matching table with visual range.

The common 1024*768, 800*600 and 640*480 resolutions of 4:3 screens are input into equation 2, and the relationship between screen size and visual distance under different resolution conditions is obtained, as shown in Figure 2.

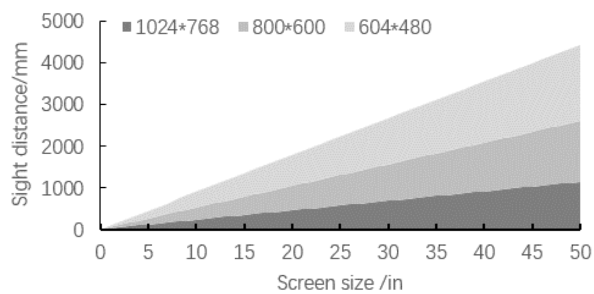


FIGURE 2. 4:3 screen resolutions and size matching table with visual range.

The field of vision refers to the spatial range that a person's head and eyes can see when looking at an object in front of them while they are stationary. When studying the relationship between the human visual distance boundary and cognition, the horizontal visual range and vertical direction are usually discussed separately. However, when studying the human eye visual fatigue and comfort, the vertical visual distance and horizontal visual distance segmentation research, instead of viewing the shape of the spatial range captured by the human eye as a cone, in this type of research, the sight

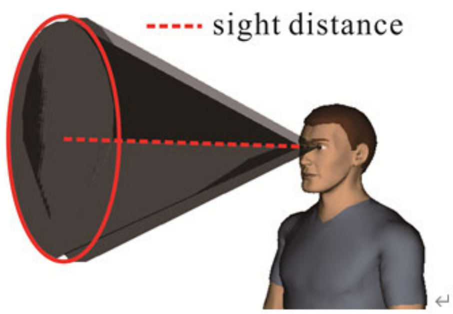


FIGURE 3. Example of sight distance.

distance refers to the distance from the eye to the bottom of the cone.

III. ARCHITECTURE OF ADAPTIVE CONSOLE DESIGN PLATFORM

A console will go through three processes from manufacture to use, that is, hardware manufacture, console design and cabin layout. This paper focuses on the discussion of console design and proposes a new console design method. The spatial condition is an important reference for the console in the overall layout of the cabin. For the console design, more attention is paid to how to provide more human-computer comfort for the operator on the basis of meeting the hardware installation requirements. In the console design, the screen, keyboard, control rod and other hardware are developed and provided by a third party. These hardware items have a fixed size. In the console design, we cannot change the size of the hardware. We can design the console only by adjusting the angle and point of hardware installation on the basis of meeting the hardware installation requirements as much as possible.

In this paper, a novel architecture is proposed that combines measurement on the hardware platform and optimization on the software platform. The hardware platform determines the size of the console in the real world. Design and optimization are performed on the software platform, which is based on the layout principles and human ocular physiological characteristics.

In the design of a console, according to the sequence of workplaces and the principle of visual priority, the position of the human eyes while a person is in the sitting position is determined according to the size of the human body. According to the visual comfort recognition of human eyes directed towards a display screen, the optimal distance between human eyes and the display screen is determined. Next, according to the comfortable range of the arm, the position of the control area and the position layout of the control keys are determined with the human body as the benchmark. Finally, the position of the work chair and the spacing between its legs are determined according to the comfort level while a person is in the sitting position and the range of movement between people. The key challenges are as follows:

- How do we obtain the sizes of different consoles?
- How do we design consoles with appropriate sizes?
- How do we evaluate the comfort of human eyes focused on a console?

To overcome the first challenge, we propose a hardware platform that can automatically acquire the sizes of different consoles. Then, we propose a console design algorithm to allow the console to meet the needs of users regarding the joint angle and muscle comfort and to reduce the physiological fatigue of a user's eyes, thereby improving the operator's cognitive efficiency and accuracy. Furthermore, we propose an evaluation metric for determining the comfort level of a human eye directed towards a console.

A. PRELIMINARIES

1) DESIGN OF THE DISPLAY SCREEN POSITION

On a desktop console requiring a high seating posture, there are two display screens: the main display screen and the secondary display screen. An operator can observe the two display screens through head rotations and eye rotations while maintaining the sitting posture. In the observation of a display screen, when the human eye rotates comfortably, text or image information on the display screen can be clearly distinguished from a comfortable distance.

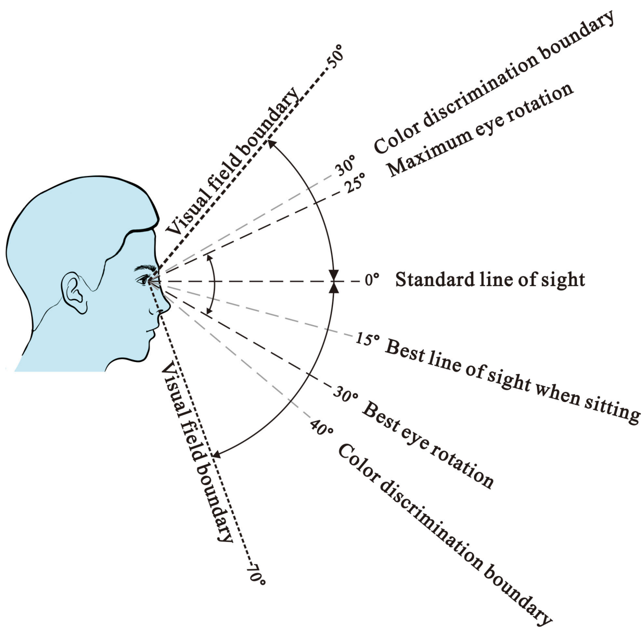


FIGURE 4. Human eye vertical visual field.

Regarding a person's vertical vision, the best eye rotation area is 25 degrees above the horizon to 30 degrees below the horizon. The best human visual angle is within the range of 10 degrees above and below the horizon [3], as shown in Figure 4. By keeping the display screen within the best visual area of the human eye and within the range of the human visual distance, the relative perpendicularity of the panel and the human visual line is guaranteed, and the eye

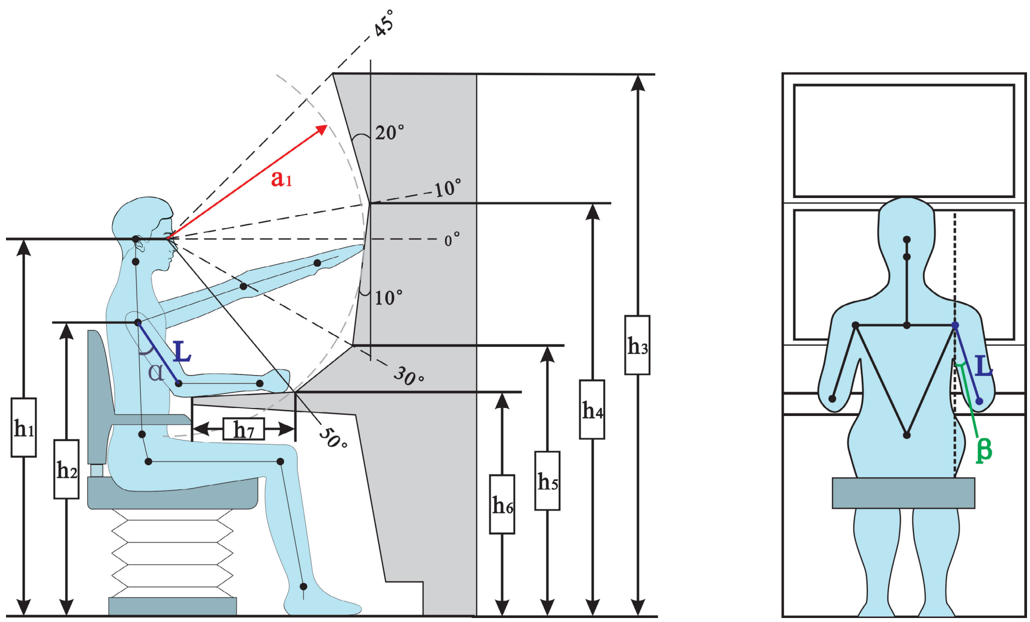


FIGURE 5. Operational posture.

moves within the best range of human eye rotation during observation. Therefore, the main display screen is set in the range of 30 degrees below the operator's horizontal line of sight, and the inclination angle relative to the vertical plane is 10 degrees. The panel is equipped with the most important display device, as shown in Figure 5. The secondary display screen is placed within the visual limit of the human eye so that the operator can observe the dynamic state of the display screen with residual light without turning his head. When the secondary display screen is observed and operated, the human head is slightly raised such that the upper boundary of the display screen is in the maximum rotation area of the human eye, thus enabling the operator to realize accurate observation of the display screen. The comfort adjustment range of the human neck joint elevation is from 15 to 25 degrees. Taking the middle value of the comfort area (20 degrees) as the head elevation angle, the secondary display screen is set within the range of 10 to 45 degrees above the operator's horizontal line of sight.

The key dimensions of the console can be expressed as follows:

$$\begin{aligned} \mathrm{h}_3 &= \frac{a_1 \sin\ 45^\circ}{\sin\ 59^\circ} * \cos 14^\circ + \mathrm{h}_1 \\ \mathrm{h}_4 &= \frac{a_1 \sin\ 10^\circ}{\sin\ 70^\circ} * \cos 10^\circ + \mathrm{h}_1 \\ \mathrm{h}_5 &= \mathrm{h}_1 - \frac{a_1 \sin 30^\circ}{\sin 70^\circ} * \cos 10^\circ \end{aligned} \tag{3}$$

2) DESIGN OF THE CONTROL ZONE

During operation, the forearm of the operator is placed naturally on the operating table. The human upper arm forward pendulum forms an angle α with the direction perpendicular to the body, and the outer pendulum forms an angle β with the direction perpendicular to the body. For a table height h_6, the projection length of the upper arm L in the vertical direction is subtracted from the eye height h_2 while the person is in the sitting position, as shown in Figure 5. When the upper arm is working while the person is in the sitting position, it hangs naturally. The comfort adjustment angle of the front pendulum and the back pendulum is 15-30 degrees, and the comfort adjustment angle of the inner pendulum and the outer pendulum is 0-20 degrees. Thus, the height h_6 of the worktable can be expressed as:

$$\mathrm{h}_6 = \mathrm{h}_2 - \left(\mathrm{L} * \cos \alpha^\circ * \cos \beta^\circ\right) \tag{4}$$

Regarding male joint comfort, the range of the upper arm forward and backward swing α is 15-30 degrees, and the range of the upper arm inner swing and outer swing β is 0-50 degrees. The above data are substituted into 3-4 for calculation, and the comfortable range for a height h_6 of the mesa is obtained.

To keep the hand properly operated and rested, in the design of the working table depth, the normal working area of the hand is 394 mm along the surface, as shown in Figure 5. Therefore, to ensure normal operation, the depth of mesa h_7 is 394 mm. At the same time, to ensure that the operation keys are in the human touch area, the static reachability of the fifth percentile operator is satisfied. The fifth percentile of the body size of Chinese men is chosen as the sum of the upper arm length and forearm functional forearm length, i.e., 623 mm along an arc.

3) DESIGN OF THE WORK CHAIR AND LEG SPACING

To keep the lower limbs comfortable, the workspace of the operating table and seat should provide a comfortable spacing between legs for the operator in the sitting position.

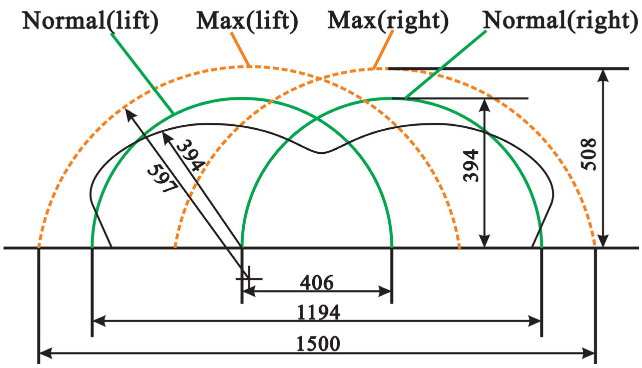


FIGURE 6. Normal and maximum dimensions of the horizontal working surface.

When a person sits in a comfortable position, his thigh rests on the seat surface, and his calf sags naturally. Thus, the knee depth under the table is the P_{95} hip-knee distance minus the thickness of the human chest.

B. HARDWARE PLATFORM

Due to the wear and tear caused by installation and use, the size of consoles of the same model often varies. To automatically acquire the sizes of different consoles, we use 3D scanners to collect data.

Various types of 3D scanners are available, each more suited to specific applications, e.g., scanning small objects with high resolution or scanning large objects with low resolution. A scan all around an object requires that either the object is moved past the scanner, e.g., on a turntable, or the scanner is moved around the object. Several types of known scanners are capable of capturing the complete surface information of objects and scenes. Generally, these scanners can be separated into three categories: photogrammetric scanners, fixed-station laser scanners and hand-held 3D shape scanners. The scanners generate data points or other structures representing the scene or object scanned, and these data can be post-processed by software to allow visualization and to generate 3D representations or 3D computer models of the scene or object.

Hand-held 3D shape scanners comprise a hand-held mobile scanner-head that is commonly manoeuvred by a user about the object being scanned. Typically, the scanner-head includes a range sensor for determining the local shape of the object by sensing the position in space of the surface points of the object relative to the scanner-head. For example, the range sensor may sense the position in space of the surface points via laser triangulation. The hand-held 3D shape scanners also comprise a position and orientation system that measures the position and orientation of the mobile scanner-head in space during the scan. The local shape information is then coupled with the scanner-head position and orientation information to enable a 3D computer model of the object to be constructed.

C. SOFTWARE PLATFORM

In the past, the console design method involved the following: analysis of the place of usage and function → determination of the basic size of the console → determination of the size and angle of each side of the console according to the ergonomic instruction manual → production and manufacturing.

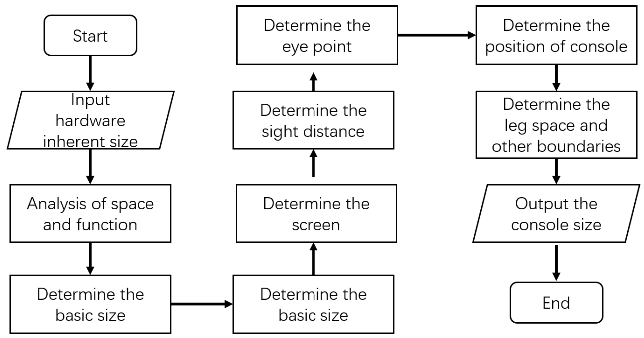


FIGURE 7. Flowchart of the console design.

As shown in Figure 7, the console design method we proposed is as follows: analysis of the space and function → determination of the basic size of the console → determination of the resolution, scale and size of the screen → determination of the sight distance → determination of the eye point (according to the eye point, the seat installation position can be determined) → determination of the screen position and console area position → determination of the leg spacing and other boundaries according to the ergonomic guidance manual size → manufacturing.

The 3D scanners automatically acquire the sizes of different consoles, and the output of the 3D scanners is the input of the console design algorithm, as follows:

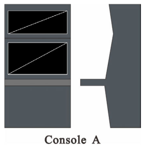
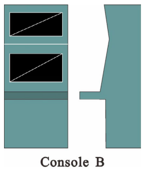
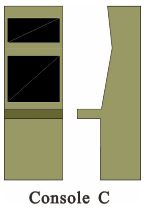
Algorithm 1 Console Design Algorithm

Input: Original Console Size $\{C_o\}$
Output: Designed Console Size $\{C_d\}$
Determine the Human Visual Distance with Eq. (2)
Design the Position of the Display Screen with Eq. (3)
Design the Height of the Control Zone with Eq. (4)
Design the Work Chair and Leg Spacing
Output: Console Size

In the previous design process, the location and function analysis is carried out first, and then the basic size of the console is determined. The size and the angle of the console are directly determined according to the ergonomic guide, and then manufacture takes place.

In our method, according to the order of the work place, following the principle of visual priority, and starting from the size of the human body, the position of the human eye while a person is in the sitting position and the visual comfort relative to the display screen according to the human eye

TABLE 1. Schematics of the three console schemes.

Console model	Console sketch	Overall size	Screen size	Screen ratio	Screen resolution
A		Large	27	16:9	720 px
B		Middle	19	16:9	1080 px
C		Small	17	1:1	480 px

are considered to determine the best distance from the eye to the display screen. Next, with the human body as the basis, the position of the control area and the position layout of each manipulation button are determined according to the comfortable range of motion of the human arm. Finally, the position of the work chair and the size of the leg spacing are determined according to the comfort level while a human is in the sitting position and the range of movement between people.

IV. EXPERIMENTS

The adaptive console optimization platform has been widely used in console optimization and engineering instances, and subjective evaluations of what feels more comfortable can be obtained from feedback regarding the optimized console. We track the physiological state of the eyes of console users and use the optical quality analysis system (OQAS) system to measure and collect the eye physiological indicators of console users using the optimized front console and the eye physiological indicators of those using the optimized console to compare the two measurements. The eye physiological index data are used to evaluate the optimization effect of the adaptive console optimization platform. The equipment used in the experiment is the second-generation OQAS, i.e., optical quality analysis system II, which is a professional ophthalmic medical testing device developed by the Visiontrics company in Spain. It is highly recognized by clinical ophthalmologists in the international scope. The equipment has achieved FDA, CE (in Europe) and CFDA (in China) certification.

Three representative console optimization schemes are shown in Table 1; these are compared to the user's eye physiological indicators. Console A is characterized by a large screen and low screen resolution; console B is characterized by a small screen and high screen resolution; and console C is characterized by an unconventional screen ratio and a low screen resolution.

To verify the usability and universality of the application of the optimized design, we selected three practical examples of the optimized design of the console, and designed a comparison experiment of human eye fatigue of the console before and after the optimization. Industrial applications are the most common. Each group of experiments is carried out independently. In each group of comparative experiments, the screen width of the console before and after optimization remains unchanged. The experiment uses OQAS to conduct a more objective evaluation of human eye comfort. This is the first time that the OQAS system has been used as an evaluation method in this field.

In each group of experiments, we first benchmark the user's eye fatigue; the second step is to set up some console operation tasks to allow users to perform fatigue tests on their eyes after completing these tasks; the third step is to allow the user to rest fully, and to restore the user's eye fatigue to similar to the benchmark index; The fourth step is to use the optimization design method we proposed to optimize the console, let the user complete the same tasks as before, and perform a fatigue test on their eyes. Comparing the eye fatigue after using the console twice with the baseline fatigue, it is found that under the same task and the same environment, the user's eye fatigue degree after using the optimized console is smaller than that of the benchmark, and the change is smaller than the user's eye fatigue degree after using the

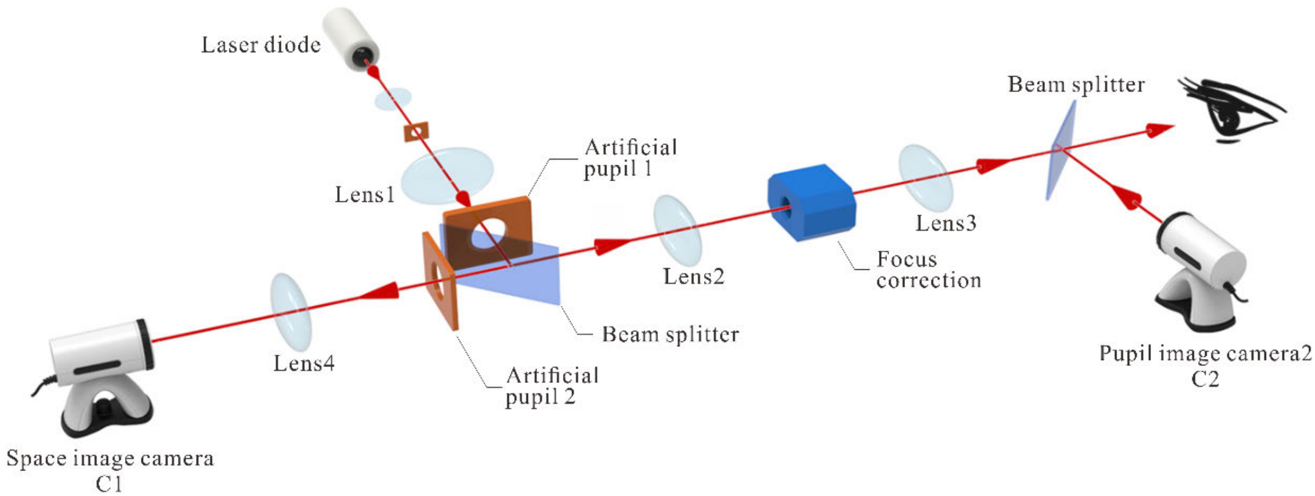


FIGURE 8. Schematic diagram of the optical quality analysis system.

original console. This proves that our console optimization method can effectively reduce the user's eye fatigue.

A. EVALUATION METRICS

The OQAS is a device that objectively measures the visual quality of human eyes based on the principle of dual-channel technology (the device principle is shown in Figure 8). Compared with other visual quality analysis methods, such as eye chart measurement and eye fatigue questionnaire measurement, the OQAS measurement results have good objectivity and reproducibility and are widely used in clinical objective visual quality analysis.

TABLE 2. Summary of notations.

Notation	Description
MTF	modulation transfer function
MTF cut-off	modulation transfer function cut-off frequency
TFA	tear film analysis
TBUT	tear break-up time
Mean OSI	mean objective scatter index
OSI	objective scatter index
SR	Strehl ratio
PA	pseudophakic accommodation
PSF	point spread function

As a more advanced objective visual quality test system, the OQAS can test a variety of indicators. The more commonly used indicators are the OSI, MTF and TFA, defined in Table2; they are widely used in optical quality analysis [19]. The OSI refers to the ratio between the peripheral light intensity of the system detecting the retinal image and the central peak light intensity, which is used to evaluate the visual quality. The MTF refers to the difference between the image and the object contrast at different spatial frequencies, i.e., imaging on the retina. The ratio of the contrast to the actual object is used to evaluate the ability of the eye to resolve the space. The TFA is the optical function test of the tear film, and the OSI value of the volunteer eye is recorded every 0.5 seconds using the OQAS instrument, with the OSI value being continuously recorded for 20 seconds. The wavy-line graph and the mean OSI value during this calculation period are calculated to evaluate the degree of tear film stability.

B. EXPERIMENTAL SETTINGS

1) BASELINE

To evaluate the performance, we consider the following baseline in our experiments: the traditional ergonomic-principles-based console design method [20], which is benchmark *A* in the experimental result tables in this paper. The baseline and our console design method have the same inherent hardware size.

2) VOLUNTEERS AND EXPERIMENTAL ENVIRONMENT

Each experiment involved 20 console users, aged 25-30 years old. All participating volunteers underwent ophthalmologic examinations involving, for example, a slit lamp and an ophthalmoscope. There were no eye diseases such as myopia, hyperopia, amblyopia, and astigmatism, no history of eye surgery, and no systemic diseases. In the experiment, when selecting the person to be tested, a console user who has good life habits and good eye habits, and the ability to balance work and rest should be selected to eliminate the differences in eye fatigue tolerance caused by certain personality factors. Since males are the main users of consoles, the experimental volunteers were all male. These volunteers were chosen because of the following:

The experiment was carried out in a laboratory with a stable environment. There was no stimulating light source, there was no noise in the room, and the temperature and humidity were within the normal range to ensure that the pupils of the participating volunteers could reach maximum dilation in the natural state. The screen brightness of the console was adjusted to each user's comfort level, and the screen

TABLE 3. Summary of experimental indicators.

Experiment ID	Console ID	Console (Control group)		Optimized console (Experimental group)	
		Before using the console	After using the console	Before using the console	After using the console
1	A	A_{st}	A_{be}	A'_{st}	A'_{be}
2	B	B_{st}	B_{be}	B'_{st}	B'_{be}
3	C	C_{st}	C_{be}	C'_{st}	C'_{be}

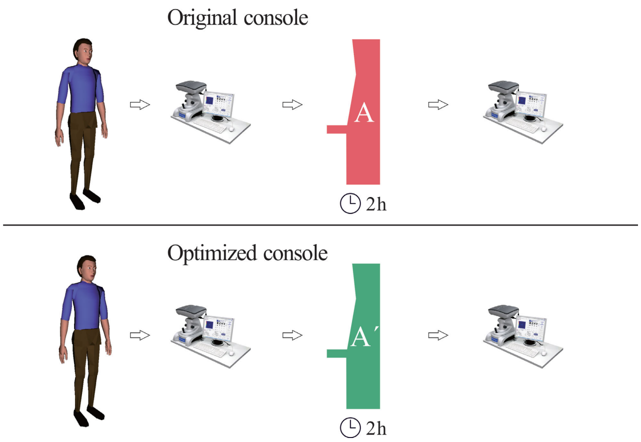


FIGURE 9. Comparison of experimental parameters of the human eye physiological indicators before and after control console optimization.

brightness of each group of experiments was the same. Before each test, we explained to all volunteers the purpose of the test, the test steps and the possible discomfort to alleviate any nervousness among the participating volunteers and gain better cooperation during the test. All participating volunteers signed an informed consent form.

3) EXPERIMENTAL PROCESS

The experiment was a comparative experiment. Users of the console before optimization were the control group, and users of the optimized console were the experimental group. The experimental flow is shown in Figure c.

Take Experiment 1, shown in Table 3, as an example. The volunteers were organized to conduct OQAS system testing at 9:00 am on weekdays, and the test results were marked as A_{st} (A-standard). After the test, the volunteers used console A to perform simulation operations without interruption. The simulation period lasted for 2 hours. After completing the operation task, the volunteers were trained on the OQAS system. The test results were marked as A_{be} (A-before), and the results of the two experimental tests were recorded. The work and work schedule for the rest of the day were the same as usual. After optimizing the design platform for the A-type console using the adaptive console, the console model was marked as A', and volunteers were asked to perform the OQAS system test at 9:00 am on the working day. These test results were marked as A'_{st}. After the testing, the volunteers continuously optimized console A' to carry out the simulation operation task for 2 hours. After completing the operation task, the volunteers were trained to carry out the OQAS system test. The test results were marked as A'_{be}, and the results of the two tests were recorded. The rest of the experimental procedure was the same as in Experiment 1, as shown in Table 3.

When analysing the test results of the volunteers before and after the console optimization, it was first necessary to compare whether the difference between A_{st} and A'_{st} was within a reasonable range to ensure that the subjects' initial states were consistent.

C. EXPERIMENTAL RESULTS AND ANALYSIS

We carried out the experiment to evaluate the statistical significance of the differences reported in the experimental results. The p-value was 0.95, showing that our results were statistically significant. In all the experimental results, most of the indicators underwent obvious changes, and the change rules of the indicators all show that the optimized console is less burdensome to the human eye. The changes in the relevant indicators of the tear film were the most obvious. The reason may be that the stability of the tear film reflects the degree of dry eye syndrome of the test subject. Dry eye syndrome is a common eye disease, manifested as eye discomfort, decreased vision, etc. These symptoms are consistent with the subjective claims of the test subjects, indicating that using a console causes different degrees of discomfort to their eyes, such as temporary dry eye syndrome. At the same time, compared with the console before optimization, a tester using the optimized console had fewer tear film stability changes and a shorter rupture time, which represent the degree of dry eye syndrome of a subject. Even for some subjects with strong eye tolerance, using an optimized console will not cause temporary dry eye.

However, not every indicator underwent a significant change. The change in PA was very small. Indeed, some PAs experienced no significant changes before and after the optimization. The reasons for this outcome are as follows:

- The short testing time and eye fatigue did not affect the ability to make adjustments;
- Because the subject had no eye disease, the suspensory ligament that controls the eye adjustment ability functioned well;
- The adjustment ability mainly reflects the degree of presbyopia of the subject, and the influence of console use on the eye is temporary; thus, these reasons did not cause the subject to be presbyopic.

1) OBJECTIVE SCATTERING INDEX

The lens, cornea, and tear film are the main sources of intraocular scattering. The OSI value can represent forward scatter

TABLE 4. Comparison of objective scattering indices of users before and after console optimization.

Console number	Subject status	OSI(OD)	OSI(OS)
A	Before using the console	0.5 ± 0.12	0.7 ± 0.11
	After using the console	2.1 ± 0.62	1.9 ± 0.51
A'	Before using the console	0.5 ± 0.11	0.6 ± 0.11
	After using the console	1.1 ± 0.29	1.3 ± 0.33

in the eye to a certain extent, reflecting the visual subjective feeling of the subject. The higher the OSI value is, the worse the visual quality of the subject, and the lower the OSI value is, the better the visual quality of the subject. It can be seen from Table 4 that the OSI value of the operator before using the optimized console is close to the OSI value corresponding to early cataracts, indicating that the visual quality of the subject was poor at this time. The measured OSI value of the control group operator was significantly improved and was reduced to the normal OSI value range.

2) TEAR FILM OPTICAL QUALITY

In the optical quality inspection of tear film, there are three angles of the average objective scattering index, a tear film optical quality change line graph and a point spread function graph reflecting the current tear film state of the test subject. The average scattering index reflects the quality of the tear film scattering, the fluctuation interval of the tear film optical quality change line graph and the tear film break time reflect the stability of the tear film, and the point spread function reflects the visual quality and subjective vision of the test subject.

In the test, the benchmark test and the tear film quality test of the eye before using the device ensure that the factors that cause physiological changes in the human eye in this experiment are caused only by the console. The results of the tear film optical quality test show regularity; thus, the representative test results are selected for analysis in this paper, and the other results are not further described.

The difference between the mean OSI value and the OSI value is that, as can be seen from Table 5, for the same task, the measured person's mean OSI value using the optimized console is less than that before optimization, which means that the subject's visual quality is degraded. The imaging results are clearer than those before optimization.

It can be seen from Figure 10 that for the same task, the trend of the tear film optical quality change line of the tester using the optimized console is more stable, and the tear film breaks are longer. This represents the low degree of dry eye syndrome, high visual quality, dryness or itchiness, redness and other clinical manifestations of the subject. The results are also consistent with the subject's complaints.

The point spread function is a diffraction spot distribution function formed by the point source passing through the optical system. It is used to describe the shape of a very distant target point source imaged on the retina. The smaller the spot area formed by the PSF is, the larger the light intensity

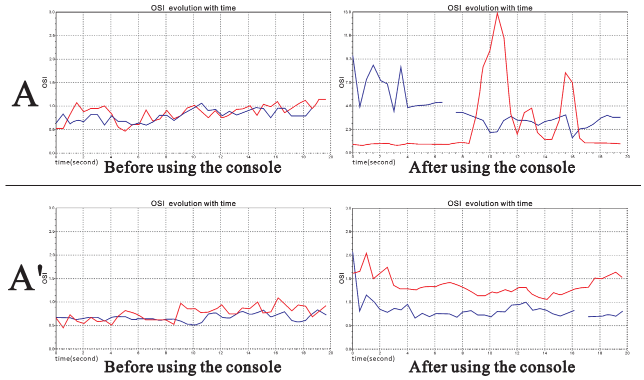


FIGURE 10. Contrast of the change in optical quality of the tear film before and after console optimization.

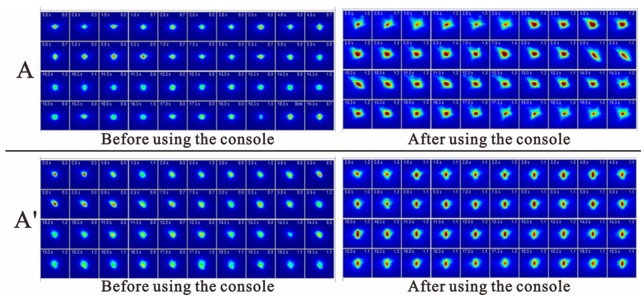


FIGURE 11. Comparison of user point spread functions before and after console optimization.

indicating the spot; moreover, the light energy loss is less after the point light source passes through the eye, and the retinal imaging is better. The PSF can be used to compare the visual complaints of each subject more objectively and effectively. Figure 11 is the record of the eye point spread function of a subject in his 20s. It can be seen from Figure 11 that the PSF area of the test subject using the optimized console is small. The area change is also small, indicating that the tear film is relatively stable, which is consistent with the realistic results of the tear film optical quality change line graph.

3) MODULATION TRANSFER FUNCTION

The modulation transfer function refers to the difference between the image and object contrast at different spatial frequencies. The MTF of the OQAS system is obtained by Fourier transformation of the PSF and decreases with increasing spatial frequency, that is, the higher the spatial frequency is, the worse the transmission capability of the optical system. The lower the contrast of the retina image is than that of the actual object, the blurrier the physiological imaging of the eye becomes, and the more degraded the visual quality is. It can be seen from Figure 12 that the measured MTF reduction value of the console is smaller than the reduction value of the pre-optimization console, which represents the retinal imaging blur problem caused by the decrease in the MTF value after the use of the optimized control console.

TABLE 5. Comparison of average objective scattering indices of users before and after console optimization.

Console number	Subject status	Mean OSI(OD)	Mean OSI(OS)
A	Before using the console	0.79±0.13	0.86±0.18
	After using the console	2.09±1.07	1.91±1.61
A’	Before using the console	0.80±0.14	0.86±0.20
	After using the console	1.39±0.11	1.15±0.14

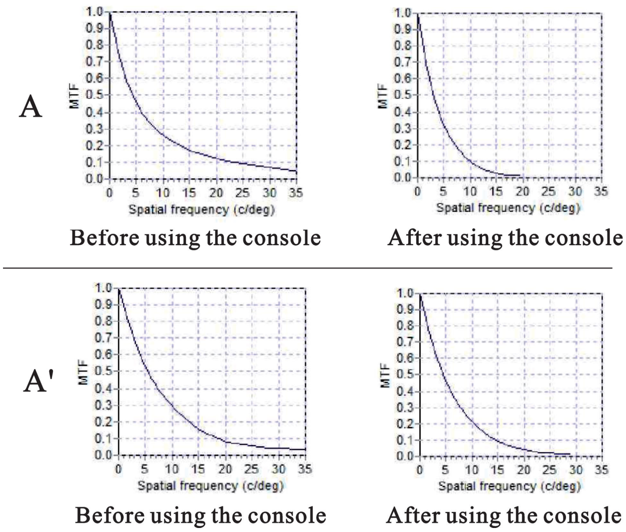


FIGURE 12. Comparison of user modulation transfer function before and after console optimization.

TABLE 6. Comparison of user modulation transfer functions before and after console optimization.

Console number	Subject status	MTF cut-off
A	Before using the console	51.90 ± 1.25
	After using the console	23.06 ± 3.02
A’	Before using the console	53.29 ± 1.11
	After using the console	30.17 ± 2.83

The MTF cut-off occurs when the spatial frequency increases to a certain value, where the transmission ability of the human eye optical system is at its lowest; the retinal imaging is the most blurred, reaching the limit of resolution. The higher the MTF cut-off value is, the greater the ability of the subject, and the stronger the optical transmission capability of the eye. A normal person’s MTF cut-off value should be greater than or equal to 30. Table 6 is a comparison of the modulation transfer function of a user before and after console optimization. From Table 6, the limit of the eye’s spatial resolution after a tester uses the original console can be seen. It has been reduced to the normal range. After optimization by the adaptive console optimization platform, the user’s eye-to-space resolution limit is increased to the normal range.

In summary, through an objective analysis of the OQAS system, it is found that the console optimized by the adaptive console optimization platform can reduce the physiological burden on a user’s eyes, as shown by the objective scattering index, tear film optical quality and modulation transfer function. The experimental results show that under the same operator, operating environment, operation task and operation duration, the objective scattering index of the console designed by the method proposed in this paper is lower than that designed by the traditional method. Moreover, the tear film optical quality and modulation transfer function are more stable after the test, which means that the console design method proposed in this paper can effectively reduce the physiological burden on a user’s eyes, for the following reasons:

- The console design method proposed in this paper is based on the human eye’s ability to identify 5000 nm yellow-green light and accurately determines the best distance between the console screen and the operator, which makes it easier for the operator to identify the content of the console display and reduces the additional eye fatigue in identifying the content of a display.
- Based on the best recognition distance of the human eye relative to the console display, the console design method proposed in this paper refers to the recommended working posture in terms of ergonomics. This method can raise the comfort level of both the operator’s eyes and body.
- A console is a special kind of equipment with small output and low versatility. The overall size of different consoles is different from the display they are equipped with. The design method proposed in this paper can adapt to a variety of consoles with different screen sizes, different screen proportions, and different screen resolutions, can carry out a targeted design according to the screen features of the console, and can accurately determine the best distance between the console display and the operator’s eyes such that the operator of the console can achieve the best eye physiological comfort.

V. CONCLUSIONS

The console is an important platform for controlling indoor operations and displaying information. It is an important device for human-computer interactions. However, previous work focused only on the joint angle and muscle fatigue of the console, and less work has focused on the distance between the user and the console screen. We propose a console design method that can make the console meet the needs of a user regarding the joint angle and muscle comfort and reduce the physiological fatigue of a user’s eyes, thereby improving the operator’s cognitive efficiency and accuracy. Experiments in the real world verify the effectiveness of our proposed method. The limitations and future work are as follows:

- The control is a special type of equipment with various models and sizes. It is found through experiments that our proposed method is suitable for the design of most control consoles, but whether it is applicable to all control console designs requires further research;
- To the best of our knowledge, this is the first work using the QOAS as an evaluation metric in this field. The experimental process is our design. However, the experiment is relatively complicated. Whether the experiment can be simplified is also the focus of our future work.

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