Technische Universität München

Master's Thesis

Depth Estimation Inside 3D Maps based on eye-tracker

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Content

Abstract: The measurement tool in the 3D map is the bridge between the map reader and the 3D map information. They can help map readers get depth, distance and angle information from 3D maps. Although many 3D map measurement tools have been designed, but little is known about their impact on map readers and verify the role of 3D measurement tools in eye tracker experiments. The authors first designed some new 3D map measurement tools to obtain the information in the 3D map, and then conducted an eye tracker experiment to verify the effectiveness of these 3D map measurement tools and the recognition mode of the experimental participants. This experiment includes an eye tracker experiment and a post-test interview. A total of 26 people participated in this experiment. The results of the experiment show the effectiveness and efficiency of the measurement tools in the 3D map. At the same time, this experiment also revealed some key points on how to improve the 3D map measurement tools.
Keywords: 3D maps; eye tracking; measurement tools; usability

1. Introduction

Spatial positioning ability is the basis for developing space ability and the basic ability required for human survival and development. Living in a spatial environment, human being shall have the ability to determine the spatial orientation of geographical objects and explore the spatial structure of objects, which is the prerequisite for solving spatial problems.

With the development of society and the advancement of technology, people are no longer satisfied with obtaining information in 2D maps, and thus 3D maps have gradually become people's first choice because of its authenticity and multi-information. However, this also bring another problem that users in virtual reality surrounding find it hard to interpret 3D symbols placed on horizontal or vertical maps. Additionally, the orientation and distance to a visible object also pose a challenge for users, which is caused by the perspective view and computer graphic influences.

In order to solve this problem, some tools in 3D maps shall be introduced. With these tools, the distance to the corresponding building, the distance between the two points of the building, and the angle formed between two points in the 3D map could be measured more easily. This makes it easier for us to read the 3D map and obtain more effective information from the map. Eye tracking has provided insight into the human cognitive process[12]. An eye tracker samples and records the user’s eye movement (gaze) data at a particular rate (e.g., 60Hz) and enables researchers to examine the user’s visual and attention processes[34]. During this work, eye tracking involves two processes: capturing eye movements and determining the gaze points[5]. In some VR and AR applications, it is sufficient to just know the 2D point of the eye-gaze, for example, selected from an on-screen menu. For other applications, like surveying a 3D map, it is important to know the 3D location where the user is looking[6]. In this experiment, an eye tracker is used to verify that the 3D map tool is effective. In the next part, the eye movement tracker will be introduced.

1.1 Development of eye movement tracking

In the early Middle Ages, the Arabs established a new discipline, physiological psychology, with the combination of mathematics, anatomy and experimental optics. Vision, as a basic part of physiological psychology, is also valued, which is also the origin of the use of equipment to track visual experiments. Since then, various theories and experimental methods and experimental devices on vision have also been rapidly applied to various researches and analyses. The earliest research on vision was influenced by the philosophy of the same period, therefore, most of them were idealistic, which greatly restricted the scientificity and objectivity of research on vision. Until the nineteenth century, Charles Bell and Johannes Muller[7] published a series of papers on eye movement research, which provided new scientific theories and scientific methods for eye movement research.

Muller and Hueck[7] discovered visual rotation and optical rotation through exploratory research. Meanwhile, Heuck also discovered the reason why the people's head turned in the opposite direction when their eyes turned to one side, and tried to explore the law. The first European Eye Movement Conference was held in Bonn, Germany, in 1981, which marked the beginning of a boom in eye movement research. Until 2005, the 13th European Eye Movement Conference was successfully held in Bern, Switzerland, and its scope of influence is not limited to Europe. It attracts eye movement researchers from all over the world to exchange academic ideas.

Looking back on the entire development of eye movement technology, there are so many research methods created for the eye movement research from the early natural observation methods, such as direct observation method, mirror observation method, peephole method and after-image method, as well as mechanical recording methods, including acoustic drum method, air bag method, and mechanical lever method. Until now, the optical recording method has slowly developed from the initial observation of idling features to the accurate measurement and recording, and finally it has become a modern eye movement technology.

Human nature is always full of ingenuity. The gaze of the human eye is often an unconscious process, and people often are attracted by those novel and interesting things. The eye tracker is an advanced physiological measurement tool that measures the gaze point, gaze time, and the path of saccade[8] (the short eye quickly moves from one gaze point to another). These eye movement data can be comprehensively analyzed through related software, providing researchers with a way to explore the unconscious and rational process of eye movement.

The eye tracker is an ideal tool for the following research: in-store shopping behavior, product packaging design, shelf design, promotion effects, store planning research; driving research, mobile device testing; outdoor advertising, TV advertising research; mailing list design research; orientation logo, navigation effect research; competitive sports, sports science research; simulator, console, training effect evaluation, novice and expert paradigm research; social behavior and group interaction research, etc.

1.2 The purpose and significance of this research

The purpose of this research is to construct and verify the 3D map measurement tool model based on eye movement data, and use the established evaluation model to divide the effectiveness of the tested 3D map tools. According to the correctness of the data of the subjects in the eye movement test, the effectiveness of the 3D map measurement tool is assessed, the cognition law of the measurement tool in the 3D map is revealed, and the 3D map measurement tool is designed from the perspective of spatial cognition.

(1) Construct and verify the 3D map measurement tool model on the basis of the eye movement data. Based on the existing research results, to the experiment design of eye movement to verify the effectiveness of the 3D map measurement tool, construct an evaluation system on the basis of the testers' eye movement experiment data. Use Bayesian structural equation model and eye movement experimental behavior indicators to verify the effectiveness of 3D map measurement tools. The low-cost ready-to-use eye-trackers[9] could be observed with great potentials.

(2) Reveal the cognition law of measurement tools in 3D maps, and then design 3D map measurement tools from the perspective of spatial cognition. All tested 3D map measurement tools are scored by applying 3D map measurement tool evaluation models. According to the experimental data of eye movement, find out the most effective measurement tool, summarize the cognitive law[10] of the measurement tool, and design a new version of 3D map measurement tool from the perspective of spatial cognition.

2. Background and Related Works

Until now, eye trackers are used in many fields, such as advertising, kinematics, geography and so on. However, the current applications of eye-tracker in geography and cartography are often focused on the exploration of the utility of the analysis tools in 2D maps, and neglect the analysis of the measurement tools in 3D maps. Therefore, in this research, the eye-tracker test on 3D maps would be implemented.

2.1 Map cognitive theory

When a reader is intent on learning a map, there are two cognitive factors taking effect. The first factor shall be the control process, which matches the map with the information already in memory and determines how the system should accomplish the task that prompts the map learning. The second one is characteristics of the memorial system, which includes the mode of representation (verbal or image) and a limited set of resources for storing and maintaining a map representation in memory[11].

Spatial cognition refers to the process of processing spatial information from the outside world to the cognitive person's mind[12]. The essence is that the cognitive person maps or reconstructs the external space in the brain, which could also be defined as the process of internalizing the cognitive result of spatial events and spatial relations into a systematic spatial knowledge structure. In the field of cartography, spatial cognition studies the information processing process of the cognizer's understanding of the various elements of geographic space, especially the shape and location of the geographic event, the spatial distribution state of the cognition, the spatial relationship between them and the cognitive process of dynamic changes in geographical events[13].

Think of human being as the CPU of a computer, the information obtained by them is regarded as symbols. Cognitive information processing theory believes that the process of human acquiring information is equivalent to the process of computer processing information symbols, that is, the entire process of input, coding, processing and storage, extraction and use of information[14]. The processing of information by human being follows a certain pattern. The earliest information processing model is mainly divided into three parts: the first part is the storage of information, which means that after obtaining external information, the information is stored in a specific location in the brain, similar to a computer Disk. The second one is the cognitive processing process, which includes several links, such as attention[15], perception, retelling, organization, and retrieval. This process integrates, transfers, and transforms information. It belongs to the internal intellectual activity of the brain, similar to various computer applications. The third one is metacognition, including the cognition, experience, monitoring and adjustment of the cognitive process, which has a significant impact on controlling the processing of information.

As a complex cognitive process, similarly, geospatial positioning is also a process of selecting, processing, coding, storing and extracting geographic information[16]. For example, in the positioning process of image geographic space, the selection is that people first perceive and process image information, processing and coding indicate that people start to construct mental maps after obtaining geographic information, and perform some complex operations on the map in their hearts, such as rotation, comparison, etc. At the end, the important information to determine the final goal is stored and extracted.

2.2 "Eye-Mind" hypothesis

Generally speaking, eyes are the first sensory system to receive information from the outside world. About 80% to 90% information is conveyed to the brain through the eyes. Vision is significant for the reception and processing of information. As the phrase said, "what you see is what you think", the process of eye movement reflects the thinking process of the brain, and the brain dominates the movement of the line of sight.

Just and Carpenter put forward the "Eye-Mind" hypothesis[17], namely that eye movement can reflect the dynamic changes of human attention. Experts believe that when there is cognitive process in the brain, the line of sight will be fixed at the position that causes this cognitive process, and the corresponding fixation time and number of fixations will increase. Therefore, the process of eye movement can reveal the inner mechanism of cognitive processing. In the field of spatial cognition, eye tracking technology has become an important research tool for a long period. With the help of eye tracking technology, it is possible to visualize the human cognitive process. At the same time, regarding the temporal and spatial characteristics of eye movement as an indicator, the cognitive process could also be converted into statistical data that can be quantified and analyzed. Researchers found that the eye movement process generally reflects six mental cognitive processes: sight search, discovery, discrimination, recognition, determination and memory search[18]. These six processes are indispensable in target search. Participants generally use certain strategies to search for potential targets as a whole within the visual range, and constantly filter information during the searching process to determine the target finally and follow the target[19]. Participants will distinguish the target by analyzing the details of the target, especially similar targets, and identify the final target based on the characteristics, and finally determine the target. In the whole process of target search, memory search will be continued, namely that, make a comparison between the target object and that in memory.

2.3 The concept of eye tracking technology

Eye tracking technology is also called gaze tracking technology, and its principle is to use multiple detection methods such as optics or machinery to obtain the subject's gaze direction. By adopting the eye tracking technology, the subjects’ behaviors of using vision to obtain information are more obvious, so that the subjects’ human-computer interaction behavior can be traced. Through records of the subjects’ gaze trajectory and gaze time, the subjects’ attention elements and attention levels to the observed objects are studied. Research shows that the distribution of attention is affected by two aspects. On the one hand, it is influenced by the experimental subjects on the subjects, which is expressed in the paper as different 3D map measurement tools. On the other hand, it is influenced by the subjects themselves and the environment, such as whether the subjects have contact experience with the online mapping system, their familiarity with the current experimental tasks, and the subjects’ emotional state, use environment, use scenarios, etc.

2.4 The principle of eye tracking technology

The monitoring of the eye gaze point is achieved by recording the reflection track of infrared rays on the eyeball. After emitted by the light source, the light would be filtered by an infrared filter, and only infrared rays can pass through; after the infrared rays pass through the half mirror, part of the infrared rays reaches the mirror, which is then emitted to the human eye through the mirror. The reflected light from the eyeball to infrared rays passes through the same mirror to a special pupil camera that can lock the eyes. The camera continuously records the infrared rays reflected by the human cornea and pupil[3], and then the image processing technology is adopted to obtain a complete image of the eyeball. After processing by the supporting software, the data of the changing line of sight, such as the first fixation time[20], the return rate, etc., could be collected, thereby achieving the purpose of line of sight tracking.

2.5 Eye movement index analysis

Eye movement is an output when the visual system is stimulated, and it is divided into two forms. One is reactive eye movement, namely that, the process from signal stimulation to eye movement is not controlled by the cerebral cortex, which is an unconscious stress response.
The other is active eye movement, namely that, the signal stimulation acts on the cerebral cortex center, and then descends to the brainstem eye movement control area, thereby consciously starting the eye movement.
The technical indicators of eye tracking technology are called eye movement parameters, and various eye movement parameters are also important dependent variables in eye movement experiments. Common eye movement parameters can be divided into qualitative eye movement parameters and quantitative eye movement parameters according to whether they are quantified.
Qualitative eye movement parameters are mostly expressed in the form of pictures, videos, etc., generally without specific data support, such as eye movement heatmaps, gaze track maps, etc.
Eye movement heatmap: similar to other heatmaps, the variable in it is the fixation time at the coordinate point. The different color rendering reflects the participants' different degree of attention to each area.
Eye movement gaze trajectory map: refers to the gaze movement route trajectory, which is obtained in the form of directed linear symbols or node numbers. Its essence is the sequential connection diagram of the gaze points of the subjects during the experiment.
When the observed object is a steady picture, the eyes will leave a series of stops on it. Between these stop points, the activity is completed by rapid eye movement. In the

entire eye movement, when the eye movement stays for more than one hundred microseconds, it is called fixation, and the visual jump between fixation points is called saccade, which is a movement where the eyeball's fixation direction changes. The vast majority of visual information needs to be watched in this process in order to be processed. Generally speaking, eye movement is a joint response of nerves and muscles after vision is stimulated by the external information. For the fact that it can measure various indicators through instruments, it becomes a bridge to research the relationship between information and vision. Movement data obtain the law of change between external information stimulation and vision.

Commonly used eye movement indicators include: Time to First Fixation, Fixation Duration, Total Fixation Duration, Fixation Count, Visit Count, Mouse Click Count, Time to First Mouse Click, First Fixation Duration, etc.

(1) The time to first fixation characterizes perception.

It refers to the time from when the stimulus material starts to appear until the fixation point first appears in the area of interest. The area of interest is where we are concerned. When determining the landmark of the building, how long it took for the trial to enter the target area of the building represents the time when the subject’s eyeballs perceive the content of the area, namely, the degree of sensitivity that arouses the subject’s visual perception.

(2) The first fixation time characterizes attention.

The first fixation time is the duration of the first fixation point that appears in the area of interest. It is the time to form fixation and perform the information processing for the first time. It is the process of the overall initial recognition of the target in the area. The first fixation time is long, because not only the subjects are attracted by the material, but also the information processing is difficult to understand.

(3) The average fixation time indicates the degree of understanding.

According to the literature, average fixation time = total fixation time/number of fixation points. The total fixation time is the sum of information processing time from the beginning of attention to the determination of the click behavior, which is affected by the difficulty of information processing and the complexity of the material.

(4) The number of fixation points reflects the degree of information processing. The greater the number of fixation points is, the deeper the degree of information processing is, but it does not mean that the stimulus material is more difficult to understand. It may also be related to the individual information processing strategy. Therefore, it is usually necessary to consider the total fixation duration.

(5) The number of fixations indicates the degree of confirmation.

The number of fixations is the number of visits to an AOI in a certain area of interest. Each visit refers to the time from the first fixation point in the area of n of the click behavior, which is affected by the difficulty of Entering the same area of interest for the second time aims at the inspection and confirmation of targets in that area.

2.6 Applications of eye tracker

Through keyword co-occurrence network and keyword statistical analysis of foreign language periodicals, it is found that the focus of empirical research on eye movement at home and abroad is concentrated on tourism advertising, cultural and creative products, network maps, and tourism hotels. Of course, some scholars also focus on exploring the brain, hybrid application of electricity, eye movement, and self-report[21].

As a new effective tool, eye tracking equipment provides a new method for psychologists to explore human mental activities with the eye tracking technology. Medical eye trackers research human mental activity by investigating human eye movement, and explore the relationship between eye movement and human mental activity through eye movement data. With the development of science and technology, more scientists have devoted themselves to the research of eye trackers in schizophrenia. In addition, in clinical application, the eye tracker has also undergone revolutionary changes in the diagnosis of schizophrenia.

The application of educational factors and teaching resources in learning and their influence on cognition have always been research hotspots in the fields of educational technology and learning science. However, traditional research is often based on the learner's self-expression, or focused on the determination of the occurrence of learner's learning through the analysis of the output results, in which the learner's learning characteristics could be further analyzed. These external data are mixed with learners' subjective color in a certain degree, and cannot represent the data when learning occurs. Therefore, it is difficult to fully reflect the motivation of teaching resources to learners to learn. An eye tracker is an instrument that can record human eye movements, and its multiple characteristics are highly compatible with education and research.

(1) Quantification. The eye tracker can objectively and fairly record the subject's gaze duration, number of gazes, and gaze point sequence and other quantitative data, which has extremely high reliability and validity and can be widely and repeatedly applied to many experiments.

(2) Applicability. The eye tracker can generate intuitive diagrams such as heatmaps and path maps. At the same time, the eye tracker supports the experimenter to define the area of interest (AOI), with the aim of obtaining the eye movement data of a specific area within a specified time.

(3) Applicability. The eye tracker is suitable for each role included in the education process. It can reveal the relationship between learner characteristics and teaching design strategies, which is beneficial to educators to find problems during teaching, and to improve teaching skills and teaching quality. Besides, it can also help teaching platforms optimize page design, reduce the waste of resources, and improve teaching efficiency.

(4) Convenience. After years of development, the current eye trackers have the characteristics of easy-to-use, automatic intelligence, friendly operation, user-friendly design, accurate and reliable data tracking, which could be exported in multiple

formats.

In the field of sports psychology, the eye tracker is used for sports psychology research. First of all, ecology is used to closely integrate the experimental situation and the real situation. At the same time, some new instruments are gradually applied to sports in real situation, which is beneficial to obtain more meaningful experimental results. With adopting the visual movement method, the practice has obtained visual information at every moment, so that athletes and referees can obtain information feedback in time, which would continuously improve their sports level, and allow coaches to guide athletes by referring to the information feedback.

At present, the mental health level of researchers in the field of sports psychology has been improved in the limitations and trends of eye trackers. The subjects' scores in depression, somatization, obsessive-compulsive symptoms, hostility, and terror after exercise were significantly lower than those before exercise; there were very significant differences in anxiety and interpersonal sensitivity.

2.7 Depth estimation

In recent years, with the innovation of computer software algorithms and breakthroughs in hardware computing power, deep learning technology has achieved breakthrough development and progress. Human beings are adopting deep learning technology to build a new era of artificial intelligence. Computer vision is an important part in the field of artificial intelligence. In essence, computer vision is connected with the solution to the problem of visual perception. To be precise, it is how to make a computer have the ability to segment, classify, identify, track, and track objects similar to human beings, acquire the ability to show discernment and make decisions. The emergence of deep learning technology provides infinite possibilities for achieving this goal. For the fact that many problems in computer two-dimensional vision are gradually overcome, the research focus of computer vision has gradually shifted from two-dimensional vision to three-dimensional vision. Depth estimation is a basic problem in computer 3D vision, and of course it is also a very challenging problem.

Depth estimation is mainly divided into two categories: traditional methods and methods based on deep learning. Traditional methods mainly rely on SFM (Structure From Motion) technology and real-time positioning and map reconstruction (SLAM, Simultaneous Localization And Mapping) technology. These two methods are very similar in principle. They both use the motion between frames to estimate the camera pose information, and then use triangulation for consecutive frames to recover the depth information of the scene. The difference is that SFM is an offline system, while SLAM is a real-time system. Traditional methods have been developed for more than ten years and have made considerable progress. They have achieved very excellent results on public data sets, and have derived a series of excellent open source system frameworks. And depth estimation, based on deep learning technology, is a method that has only been proposed in recent years, and it is also a current research hotspot in 3D vision. Train a convolutional neural network (CNN, Convolutional Neural Network) with the application of a large amount of data, and the network model has the ability to predict the depth of the scene, thereby achieving the goal of monocular depth estimation. In this research, the depth estimation is achieved by the tools in the 3D maps, which is different from the former 2 methods. Eye tracking is compelling for interaction as it is natural for users to direct their gaze to point at targets of interest.[22]

3. Methodology

3.1Eye-tracker in this research

The experiment applies Gazepoint GP3 eye tracker, which is a screen-type eye tracker with a sampling rate of 60Hz, which can accurately capture the position of the human eye. The device is suitable for various qualitative and quantitative real-time eye movement observation research[23].

Figure 1.The Gazepoint GP3 Eye Tracker

3.1.1 The reason why we choose it[23]

(1) Easy installation and wide applicability
The eye tracker can be directly attached to the bottom of the notebook or adaptable monitor screen. The host is designed with small and compact size, which increases its portability.
Provide a mounting bracket to support the installation and configuration of a variety of screens;
Connect it to the computer with USB cable and network cable, and no more operations are required for configuration;
The eye tracking data processing can be performed in a controlled environment through the attached external data processing module;
Support Windows system;
The calibration[2] process is automated, simple and fast.
(2) Behavior capture sensitivity
The eye tracker is non-invasive, and the subject does not need to wear eye movement recording equipment.
It can accurately collect eye movement data from short distance to long distance; Support fast and large head movement behavior;
The eye tracking calibration process is automated and stable, with high success rate, which reduces the time cost of repeated calibration.
(3) High sampling accuracy
The accuracy of the data collected by the eye tracker is high, and there are no constraints on the height and age of the subjects.
The eye tracking data can be accurately captured no matter how the subject's head moves quickly or slowly, and the amplitude changes rapidly;
Preferable adjustment to changes in light, environment, which makes it possible to track the movement of subject's head, with the aim of ensuring the accuracy of the data;
The adaptive dual camera system supports automatic selection of bright pupil or dark pupil tracking.
Regardless of the tester’s race or whether they wear glasses, there is such limitation for the eye tracker, which contributes to a wide range of compatibility.

3.1.2 Information of Gazepoint GP3

Table 1. Gazepoint GP3 Parameters

Angle Accuracy	0.5-1 degree
Sampling Accuracy	60Hz
Calibration	5 points
	9 points
API	Standard

Recommended Screen Size	26”
Movement Range	25cm (horizontal) x 11cm (vertical) movement the depth movement with a range of ±15cm
System Requirements	Intel Core i5 – 8th generation or faster, 8GB RAM Windows 7, 8.1 or 10;
Working Distance	65-80cm
Track Recovery Time	<50ms
System Delay	<50ms
Output Data	Timestamp x/y coordinates pupil diameter

Size	Ultraportable – 320 x 45 x 40mm
Weight	145g
Interface	USB 2.0
Installation Method	It can be attached to an ordinary screen or notebook; or use a desktop bracket installation kit to fix the eye tracker on a desk or a tripod.

3.1.3 Installation of Gazepoint GP3

1. Connect tripod and cables to GP3 unit.
2. Screw the tripod to the GP3 with the thumbscrew.
3. Connect USB DC power cable and USB data cable to the corresponding position.

3.1.4 Position GP3 and connect it to computer

Connect the two USB cables directly to computer. (Note: cables shall be connected without use of a USB hub)
Position the GP3 on desk or laptop, centered and approximately arm’s length (65cm or 25in) away from the user.
GP3 shall be angled and pointed at the user’s face.
GP3 shall be 40cm (15in) lower than the user’s eye level so it can point at an upwards angle towards the eyes.

Avoid bright lights or sun pointing at the GP3 or the user's face. The GP3 shall be operated in a dark room.
If the user is wearing glasses, bring the GP3 closer and point upwards at a steeper angle to avoid reflections[24].

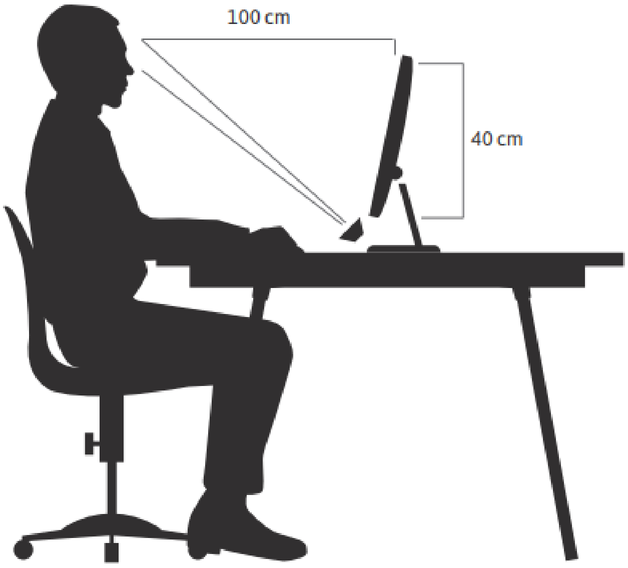


Figure 2. The perfect pose of the participants

3.2 Gazepoint Control

When running the Gazepoint GP3 eye tracker, Gazepoint Control is one of the two programs required operation. Gazepoint Control acts as a "power switch" for the IR LEDs and camera, and processes the images captured by the camera to estimate the point of the participant's gaze on the screen. So when we are collecting data, Gazepoint Control needs to be running, but shut down when data are analyzed at a later time.
Please note: if we want to switch to Gazepoint Analysis and conduct the experiment, Gaze point Control shall be minimized. Failing to do so will keep the calibration image on the screen, which would cause unreliable results from the experiment.
Most of the works done by Gazepoint Control is automatic and require no monitoring or input from the researcher. Nevertheless there are still 4 parts that need to be controlled: Calibrate, Gaze Pointer, Select Screen, and Switching the tracker type.

Start the Gazepoint Control, as shown in Figure 3.

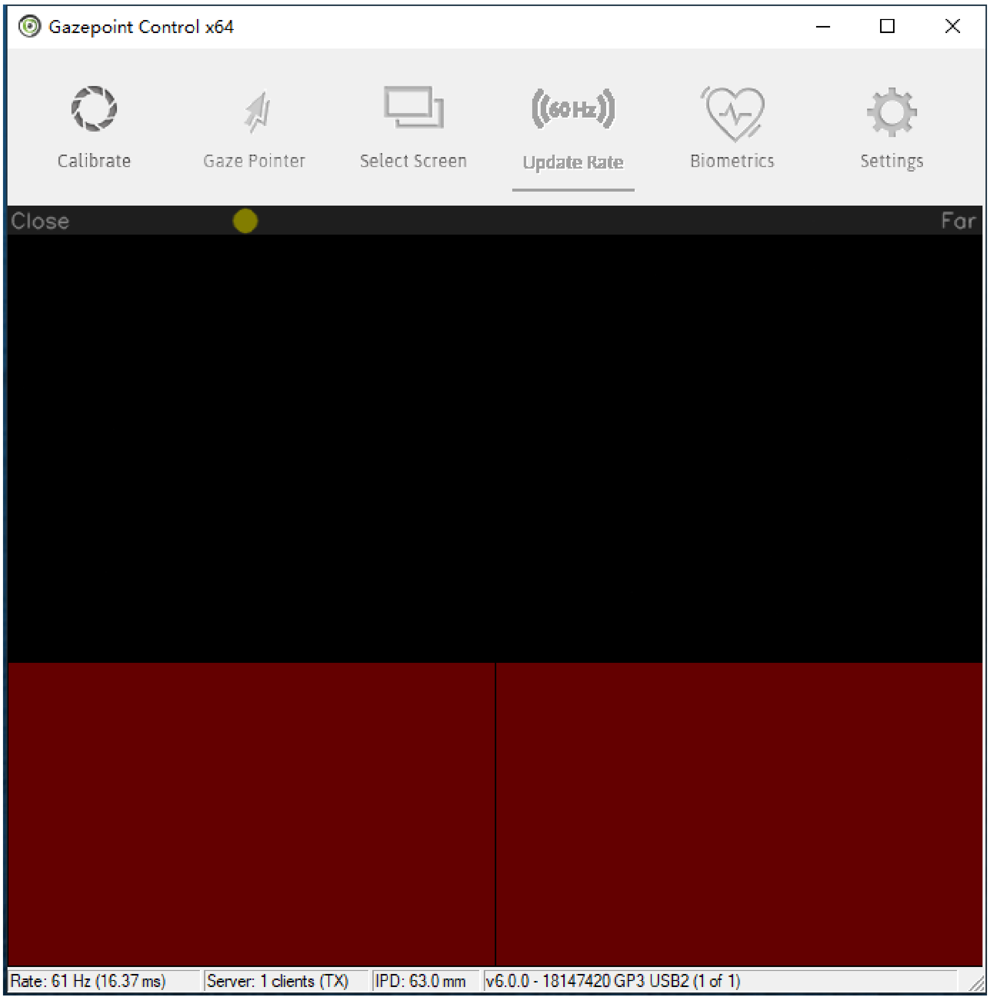


Figure 3. Screenshot of Gazepoint Control

When the Gazepoint Control is started, the camera inside the Gazepoint GP3 begins to work. The window on the screen shows four important information: Distance of Participant, Camera View, Right Eye Capture, and Left Eye Capture.

1. Distance of Participants: The ball between "close" and "far" will give us a rough estimate of the distance between eye tracker camera and the participant's eyes. In an ideal condition, the color of the ball shall be green, near the center of the spectrum. This will provide us with the installation of the Gazepoint GP3 camera.
2. Camera View: When we see this display on the screen, we could make a conclusion that the camera in GP3 is able to work. We will want to position our participant to appear in the center of the display window. With the help of the ball between "close" and "far", we now could define the physical area where our participant's eyes should be located.
3. Right Eye Capture: this display zooms in what Gazepoint Control is believed to be the right eye of the participants. You can monitor the eye tracker's ability to discern the participant's pupil and corneal reflex in this display.

4. Left Eye Capture: This display zooms in what Gazepoint Control is believed to be the left eye of the participants. You can monitor the eye tracker's ability to discern the participant's pupil and corneal reflex in this display.

3.2.1 Select Screen

As we have 2 screens, we could use the "Select Screen" button to quickly switch the researcher's screen to the experiment screen, on which the calibration and experimental stimuli will be presented to the participant. When we click the button, we could see a small, black window listing the display's dimensions.

3.2.2 Calibrate

Once the participants is seated in the proper position where the camera in Gazepoint GP3 could monitor and the experiment screen is selected, a calibration needs to be executed to make the Gazepoint Control calculate the participant's point of gaze. To perform a calibration, make sure the participant is ready well and click the "Calibrate" button. Figure 4 will appear on the experiment screen once the participant completes the calibration:

Figure 4. The Screenshot after Calibration

If the calibration results are unsatisfactory, the entire calibration could be run again by pressing the “c” key. If it’s necessary to recalibrate one point, simply click on the point needing to be recalibrated and Gazepoint Control will rerun the calibration for that one point. If the previous calibration is the desired result, but another calibration is accidentally performed, just press the “u” key to undo the most recent calibration and accept the previous calibration.

3.2.3 Gaze Pointer

The “Gaze Pointer” option allows researchers to set the mouse pointer under the control of the participant’s point of gaze. To regain the control of the mouse pointer, simply block the camera sensor’s “view” with your hand and use the mouse to turn the “Gaze Pointer” option off.

3.2.4 Switch Tracker Type

The “Switch Tracker Type” option allows researchers to switch between multiple eye tracker models created by Gazepoint. As of this manual was composed in former times, the Vision Lab only uses the GP3 eye trackers. Thus, this option will be used only if and when new
eye trackers are purchased.

3.2.5 Feedback information

Frame time:
It shall be ~16.6ms (60Hz). If the value is larger, more CPU power may be required.
Server:
This indicates how many clients are connected and if data is being used

3.3 Participants

26 students or employees from Technical University of Munich participated in this experiment. They were told that they could suspend the trial at any time. 24 of them

had normal or corrected-normal eyesight. After the experiment, two of the participants had severe astigmatism and strabismus, who are not suitable for experiments[25]. We found that the eye-tracking ratios of 24 participants were more than 80%, so we have a 24 persons' data. Among the 24 participants, there were 12 males and 12 females. Their average age is 25.5. They have a diverse educational backgrounds and have different majorities.
Six of the participants have a bachelor's degree, 12 of the participants have master's degree, and 6 of the participants have doctor's degree. 9 of the participants major in Geoscience and 15 of the participants major in other subjects.

3.4 Apparatus

In this research, a Gazepoint GP3 eye tracker was adopted. And with the help of Gazepoint Analysis UX edition and Gazepoint Control, the eye movement data could be collected. Some details of Gazepoint GP3 could be found in the former chapter. As shown in Figure 3 and 4, the eye tracker was installed rightly under the center of the monitor. In this research, 2 monitors is equipped, with one for the participants and the other for the controller. The experiment environment was set up in the eye-tracking lab in Technical University of Munich. The experiment lab was in a stable and quiet condition, with scattering light during the experiment.

Figure 5. A Picture Showing the Experiment Environment. (A participant (left) was doing the eye-tracking experiment with the Gaze Point GP3 eye tracker, while a controller (right) was observing the eye and mouse movements of the participant on another screen.)

3.5 Benchmark Tasks and AOI settings

After analyzing the existing 3D map measurement tools, the tasks of this experiment are divided into two large groups, with the aim of verifying the function of the existing 3D map measurement tools and whether the newly designed 3D map measurement tools are more effective. In this experiment, the first group includes four big tasks with 11 questions in total. These questions fall into two categories. The first category aims to measure the distance between two points in the 3D map, while the second category aims to measure the depth of two points in the 3D map. The second group includes two big tasks with 3 questions in total. These tasks are also divided into two categories. The first category aims to measure the distance between two points in the 3D map through a newly designed tool, while the second category aims to measure the angle formed by two points and eyes. All of these questions will have a correct answer. Participants use the tool to measure and finally choose one of the four options that they think is the closest to the correct answer.

The execution of these proposed tasks involves different search areas, querying types, cognitive operations, and tool interactions. In each of these tasks, the questions are becoming more and more complex. Q1, Q2, Q4, Q5, and Q8 require participants to only find a value of a point. Q3, Q6, and Q7 require participants to compare 2 values. Q10, Q11, Q12, Q13, and Q14 require participants to find the value of 2 points and make a comparison between them.

At the same time, in this part, the scenes that appear in the task and their AOI settings will be displayed. In Group 1 Task 1-3, they contain 3 AOIs. The AOI Question part includes the part of the task description in the figure. The AOI Option section includes the options in the figure. The AOI Object contains the target object in the figure. In Group 1 Task 4 and 5 and Group 2 Task 1 and 2, they contain 4 AOIs. The AOI Question part includes the part of the task description in the figure. The AOI Option section includes the options in the figure. The AOI Object contains the target object in the figure. AOI Tool contains the measurement tools in the figure. Since AOI Tool and AOI Object will have overlapping areas, an AOI Object-Tool area will be added when processing data. Besides the parts not included in these AOIs, they could be defined as AOI NULL to facilitate the data processing and visualization of the eye tracker data.

Group1 Task 1 Buffer zone[26]

The buffer zone is a kind of influence or service scope of a geospatial target, specifically referring to a certain width of polygon around the point, line, and area entity.

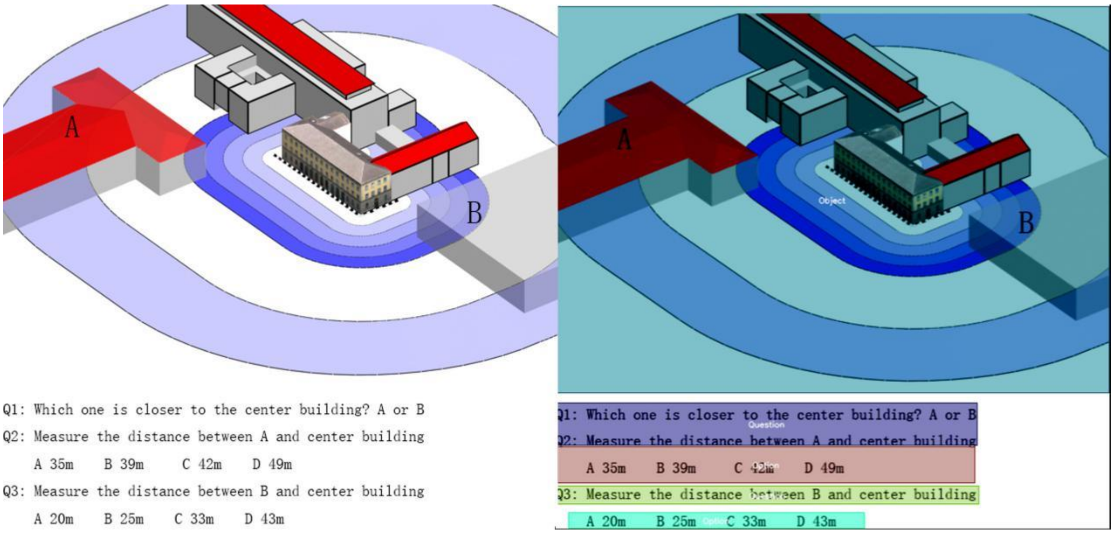
In this image, each buffer represents as10m, with AOI settings shown in Figure 6(b).

Q1: Which one is closer to the center building? The translucent square building or the red T-shaped building?

Answer: The translucent building.

Q2: Measure the distance between the red T-shaped building and center building.

Answer: 42m.
Q3: Measure the distance between the translucent building and center building.
Answer: 33m.



(a) (b)

Figure 6. 3D Map in Task 1(a) and its AOI Settings(b)

Group1 Task 2 Scale bar[26]

The facade scale bar is a perspective scale bar, whose course is aligned along the edges of the building. Therefore, when the viewing position changes, not only the building but also the scale bar adapts to the perspective distortions and replaces the classic scale bar from the map legend, which is unusable for perspective space.

In order to ensure readability from any viewing direction, a scale bar is built up along the edge in a standing and lying form. In addition, double the segment size and enlarged numbering appear for every tenth scale segment. The facade scale bar enables the building dimensions and signature positions to be determined in the map drafts. Their use is limited to flat facade maps, because physical map designs can partially or completely cover the adjacent scale forms. And the AOI settings is shown in Figure 7(b).

Q4: Measure the distance between the red points and horizontal scale bar.
Answer: 7m.
Q5: Measure the distance between the red points and vertical scale bar.
Answer: 16m.

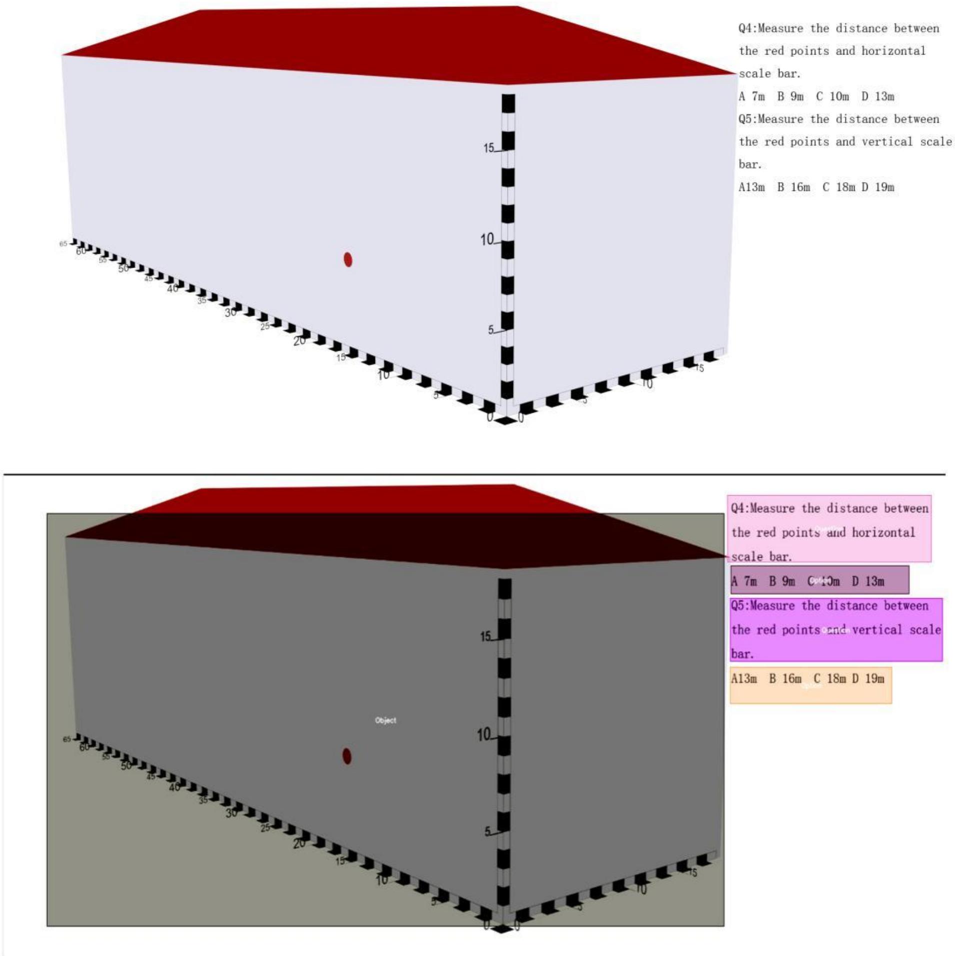


Figure 7. 3D Map in Group1 Task 2 (the Upper one) and its AOI Settings (the Lower one)

Task 3 Grids

The perspective edge grid is a comparable element to the scale bar. Like the scale bar, this is aligned with the edges of the building, with the difference that the lattice structure rests on the building as a floor lattice or as a standing lattice. Due to the limited urban representation in the immediate vicinity of the facade, and the space limited by the facade and the rather large-scale thermal structures, the expected number of structures to be classified is limited and the detail density is in the later facade map. And the AOI settings is shown in Figure 8(b).

Q6: Measure the horizontal distance from the red cone to green cone.

Answer: 14m.

Q7: Measure the vertical distance from the red cone to green cone.

Answer: 13m.

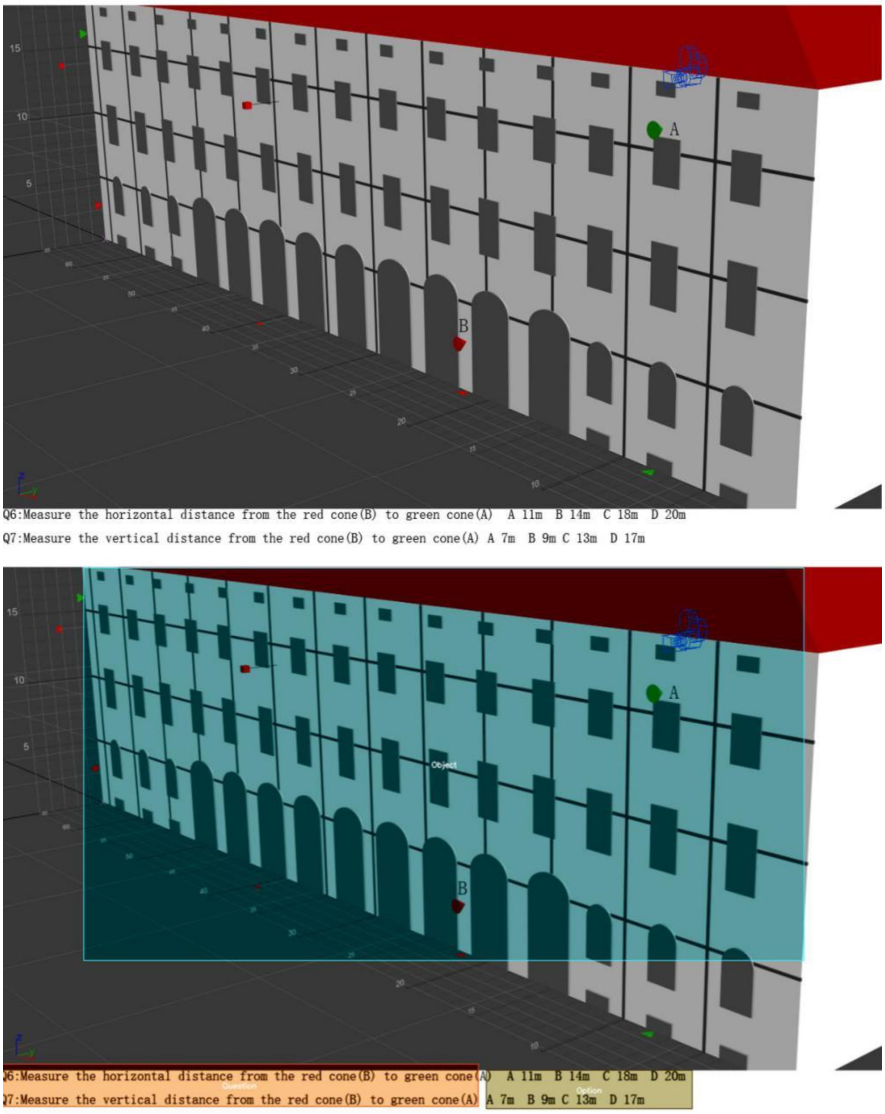


Figure 8. 3D Map in Group1 Task 3 (the Upper one) and its AOI Settings (the Lower one)

Group1 Task 4 Distance fan

The distance fan spreads from the camera origin along the viewing axis as a colored circular sector. This is built up symmetrically along the visual axis on both sides by concentrically equidistant circular arcs with colored circular sectors in constant circular arc length. For the construction of the individual circular sectors to form a distance fan, the mathematical relationship reduces the opening angle α as a function of the growing circle radius *r*. This, on the one hand, guarantees a fixed arc length *L*, on the other hand, maintains a steadily increasing division ratio for each half of the subject[26]. And the formation process of distance fan is shown in Figure 9 and AOI settings in Figure 10(b).

Q7: Which one is closer to us?

Answer: A.

Q8: Measure the depth from our view to A.

Answer: 24m.

$$L = 2 \cdot r \cdot \pi \frac{\alpha}{360°} \qquad L: Arc\ length\,(const)$$

$$\alpha = \frac{180° \cdot L}{r \cdot \pi} \qquad \alpha:\ Opening\ angle$$

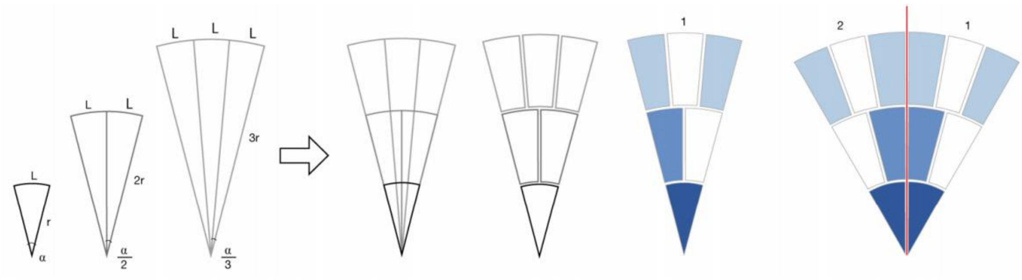
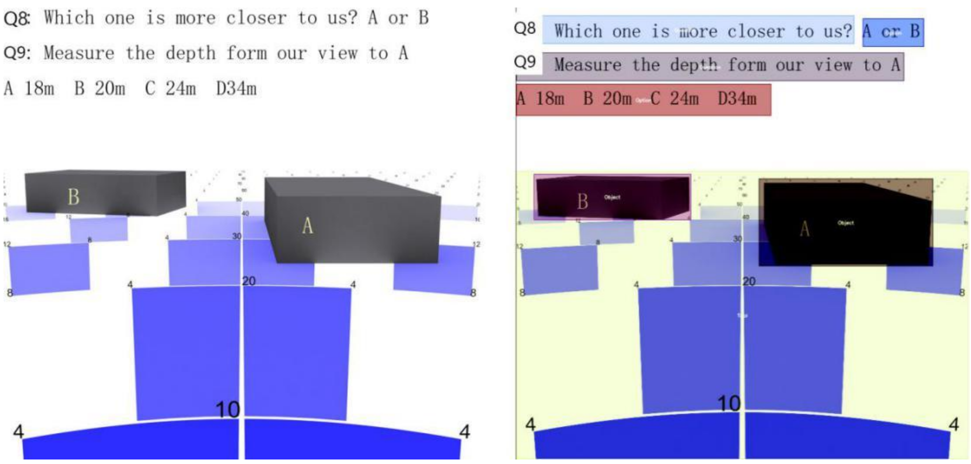


Figure.9 The Formation Process of Distance Fan



(a) (b)

Figure 10. 3D Map in Group1 Task 4 (a) and its AOI Settings (b)

Group1 Task 5 Scale bar + Distance fan

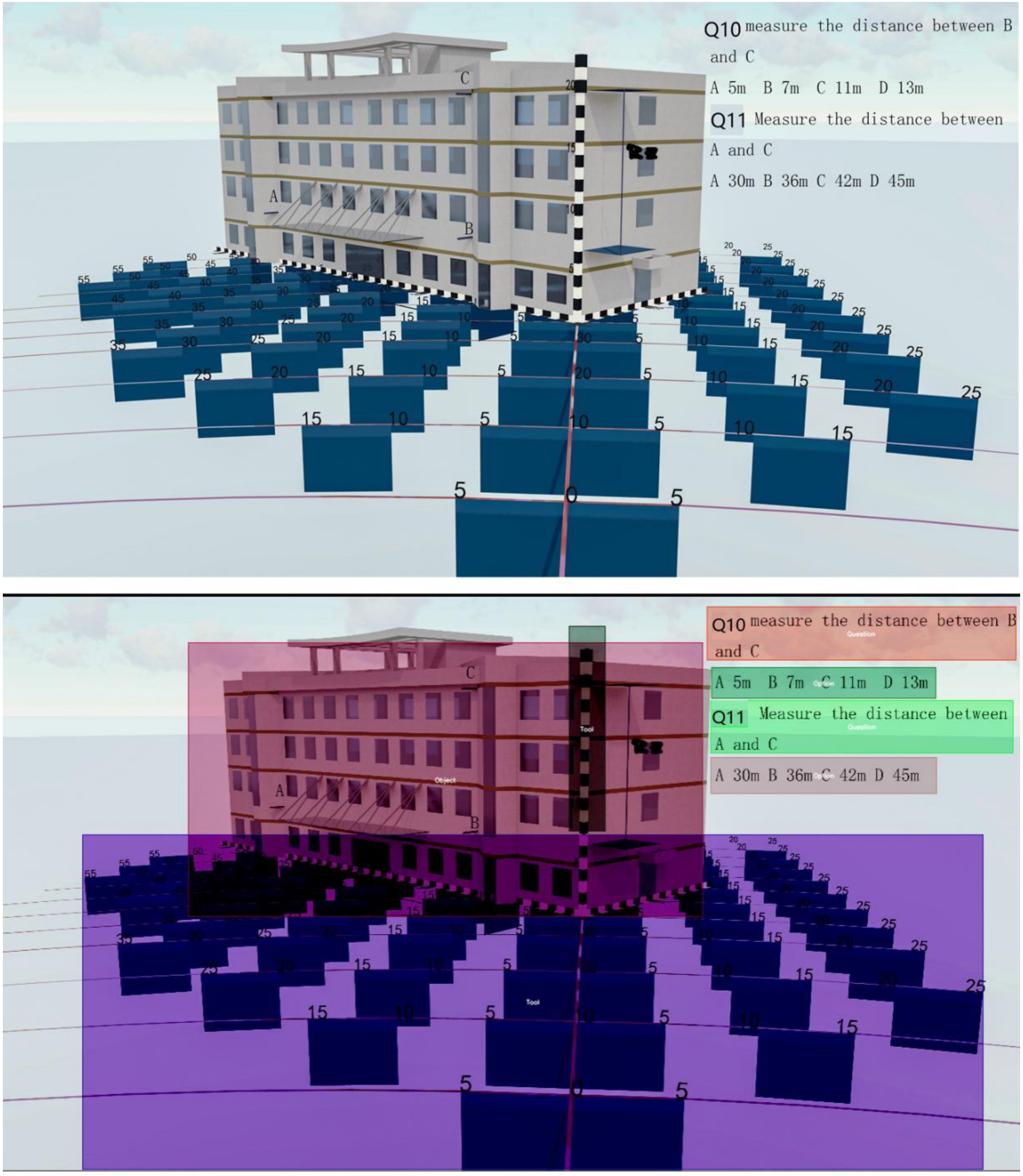


Figure 11. 3D Map in Group1 Task 5 (the Upper one) and its AOI Settings (the Lower one)

Q9: Measure the distance between A and B.

Answer: 34m.

Q10: Measure the distance between A and C.

Answer: 36m.

Group2 Task 1 Circle like scale bar

The idea of this 3D map distance measurement tool came from a scope. When I use the scale of the tool above to measure, I find that it takes time to find the target to make a vertical line to the scale. And due to the perspective angle, the vertical line may not be so accurate and just fall on the target. The projection point of the scale.

And when using the scale bar, I found that when measuring the distance between two targets that are not parallel to the scale bar, the scale bar is difficult to be applied and only an estimation value for the distance could be obtained. Therefore, this sight-like scale is designed with the sight as the origin. Due to the existence of the 45 scale in the oblique direction, it is more convenient for us to estimate the distance between any two targets. And the AOI settings is shown in Figure 12(b).

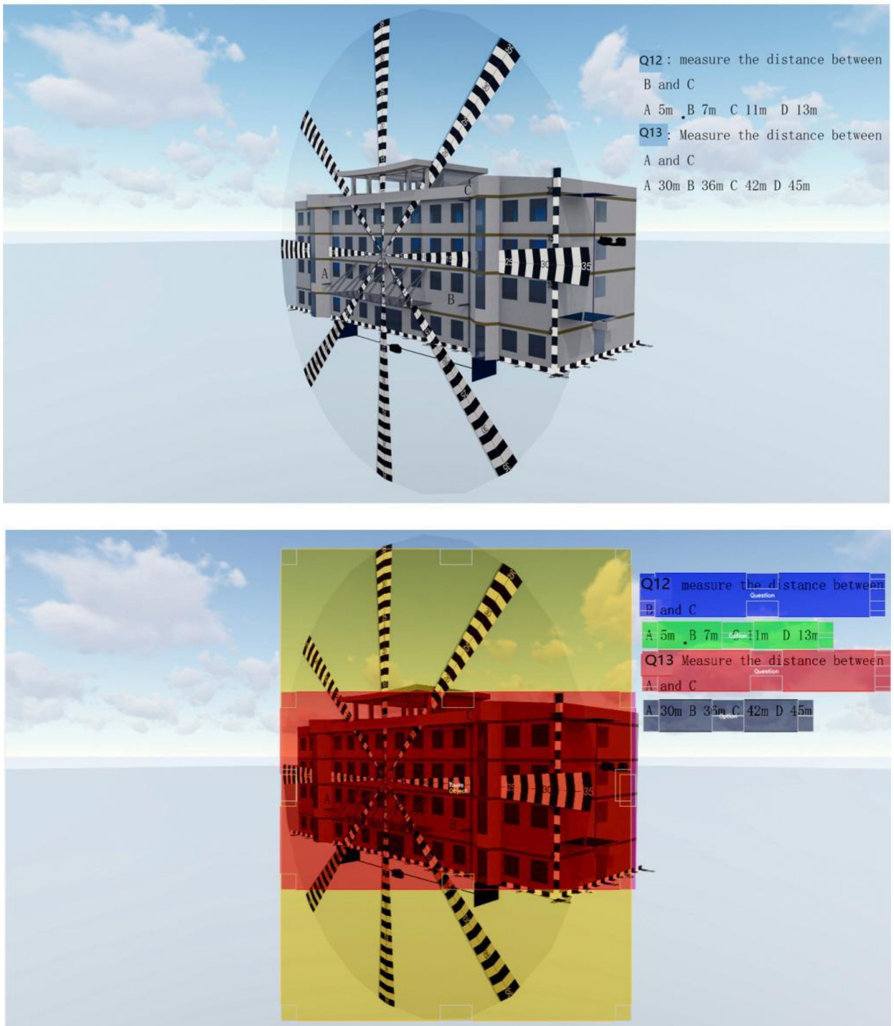


Figure 12. 3D Map in Group 2 Task 1 (the Upper one) and its AOI Settings (the Lower one)

Q11: Measure the distance between A and B.

Answer: 34m.

Q12: Measure the distance between A and C.

Answer: 36m.

Task 7 Angle calculator

The angle calculator is inspired by an FPS game Player Unknown's Battlegrounds. In this game, participants can easily find the enemy's position by using the similar angle calculator at the top of the screen. Suppose we are facing a building in a 3D map, and the angle between the two sides of the building and where we are standing is 30 degrees, then we take ourselves as the center of the circle and rotate the line of sight by 5 degrees, and mark the position where the line of sight meets the bottom of the building as 5 degrees, and then turn again until we reach the other boundary of the building, and an angle calculator could be formed at the end. The process is shown in Figure 13.

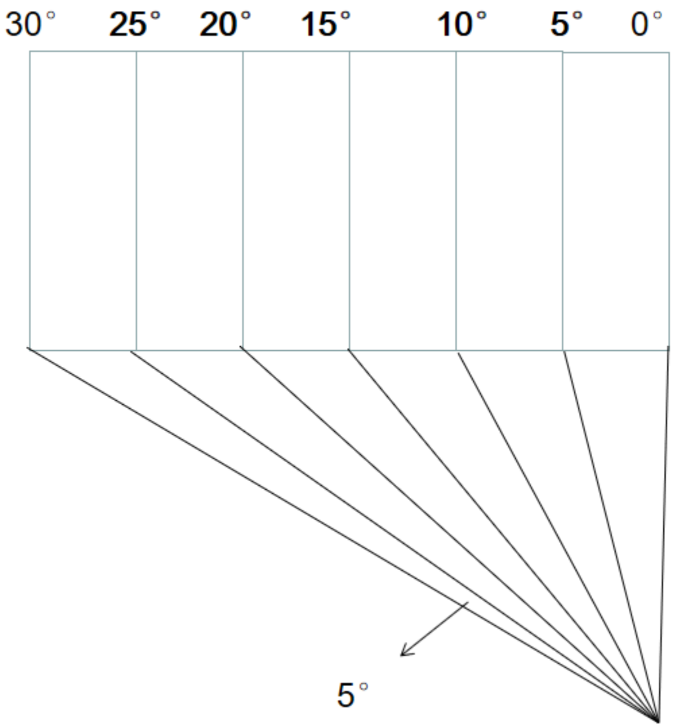


Figure 13. The Formation Process of Angle Calculator

Figure 14. 3D Map in Group 2 Task 2 (the Upper one) and its AOI Settings (the Lower one)
Q13: Measure the angle formed by A&B and our view.
Answer: 15 degrees

3.6 Procedure

The experiment started on November 21, 2020, at the 3704 Eye Tracking Laboratory in Technical University of Munich. The laboratory is quiet and protected from light, which is very suitable for eye trackers to track the pupils of human eyes, and is beneficial to improve the accuracy of experimental data and avoid the phenomenon of pupils not being tracked due to reflection. This experiment was conducted in an orderly manner. All participants performed the experiment one by one, in order to eliminate interference from other participants. Before the experiment starts, all participants will be told that they can withdraw at any stage of the experiment. This experiment consists of six stages: preparation before the experiment, introduction, adjustment of the eye tracker, calibration, task-solving, and interview[27]. Each stage is carried out immediately after the previous stage, with no gaps in between. In this part of the paper, each step will be provided with detailed introduction.

Preparation. Before the start of the experiment, in order to eliminate the influence of the participants' mood, all participants will get adequate relaxation and rest before the experiment. During their break, all participants will be informed of the data protection policy of this experiment, and all data will be used only in this paper. In addition, the participants will be informed of how much time this experiment will consume, what the tasks of each stage are, and what kind of data the eye tracker collects. If the participant agrees with that, the experiment will be carried out continuously. Then, participants will be provided with a form for collecting their personal information, such as gender, age, education level, and major, which is beneficial to analyze the collected eye tracker data.

Introduction. In this phase, the participants will be informed with the specific content of this experiment. These contents include how to use the tools provided in the map to measure 3D maps, and how many meters each buffer zone represents. In the process, if participants have questions about 3D map measurement tools, some explanations will be made for them to ensure that the data obtained in the experiment is valid. If there are questions that will affect the results of the experiment, participants will not be informed.

Adjustment of eye tracker. In this experiment, for the fact that some participants wear glasses and the glasses will reflect light, the eye tracker will not track the pupils of the participants, which will affect the results of the experiment. Therefore, before proceeding with the calibration step, the position of the eye tracker shall be adjusted to ensure that the adverse effects would not occur when participants look at the corners of the computer screen.

Calibration. First of all, the participants will be asked whether the current position is comfortable, and then let them slowly adjust the posture, guiding the ball in the Gazepoint Control software to turn green. The participants would be instructed to try to maintain this position, allowing a small range of head rotation. Then the participants will be asked whether they are ready to make corrections. If the participant is ready, click the Calibration button and let the participant's gaze track the white circle that appears on the computer screen. In the final screen, let the participants manipulate the green traces that appear on the screen. If they feel that the manipulation is smooth and precise, then the next step would be carried out. If it is not very precise and the traces are a bit jerky, repeat this step until the experimental requirements are met.

Task-solving. In this phase, the eye movement data of experiment participants will be collected. In the previous introduction, all participants are divided into two groups.

The tasks in the first group consist of 5 pictures and 10 questions. The tasks in the second group consist of 2 pictures and 3 questions. After the experiment starts, they will read the 3D map that appears on the screen, then apply the measurement tools given, and finally answer the questions that appear. Their answers will be recorded by the experiment controller, who will remind you how much time is left for each task during this process.

Interview. After the eye tracking data collection is over, the experiment participants will be asked to conduct a small interview. First, they will be asked whether they are confident in their answers to the questions. Then, ask which tools they find most useful during the experiment. Finally, they will be asked about what improvements can be made to the measurement tools in these 3D maps, and what they don't understand in this experiment that need to be added.

3.7 Method of Analysis

The effectiveness of the measurement tools in the 3D map is evaluated by analyzing the eye movement data of all experimental participants, as well as the interview data and question answers. In this paper, the key points shall be the analysis of the 4 issues: (1) the attraction of the 3D maps; (2) the effectiveness of the measurement tools in the 3D map; (3) the recognition mode of the participants when solving the problem; and (4) the participants' attitudes towards the tools

These 4 issues will be explained in details: (1) the attraction in the 3D map can be well displayed by the heatmap and fixation map. Both of these visualization methods[28] can be directly implemented in the software Gazepoint analysis. (2) The effectiveness of the 3D map tools is measured by the correctness. Firstly, the success rates of the participants among the different 3D map measuring tools are compared. Secondly, the success rates of participants among the different participants groups are compared. (3) The recognition modes of the participants when solving the problem are measured by the fixation sequence and the transition and return probabilities among the Areas of Interest (AOI) in each task. According to the goal of the research, 4 AOIs shall be chosen in each image, including AOI Question, AOI Options, AOI Tools, and AOI Objects. According to[29], the selected metrics[30] of the eye movements are listed in Table 2. In this experiment, the sequence chart[31][32] is adopted to visualize the sequence of the fixations[33] of each AOI. And in this sequence chart, different color represents different AOIs. Based on the Markov chain from Vu T. Tran's method[34], another method is adopted to visualize the transition probability. Through this method, the recognition pattern of the experimental participants could be observed and conclusions will be reached. (4) After the experiment, the participants would have an interview. From the interview, the drawbacks of these tools could be obtained and relevant adjustments to these tools will be made.

Table 2. The Selected Eye Movement Metrics

Metric	Description
Gazepoint	Gaze points show what the eyes are looking at.
Heatmap	Heatmaps are visualizations which show the general distribution of gaze points. They are typically displayed as a color gradient overlay on the presented image or stimulus.
Sequence	The order of all the fixations and scales within an AOI
Transition	The movement from one AOI (itself) or to another AOI
Dwell Time	Dwell time quantifies the amount of time that respondents have spent looking at a particular AOI
Revisit	This is a transition inside an AOI itself.
Transition Probability	The probability of the fixation moving from one AOI to another AOI.

4.Evaluation Results

In this part, a detailed analysis will be made on the eye movement data obtained from the experiment and the feedback of the participants. More specifically, in this part, more attention shall be paid to the results from the following parts: (1) The participants' fixations in 3D maps; (2) successful rate of the tasks; (3) the participants' recognition pattern when they are undertaking the tasks; (4) the feedback from the interview.

4.1 Fixation and Heatmap in 3D maps

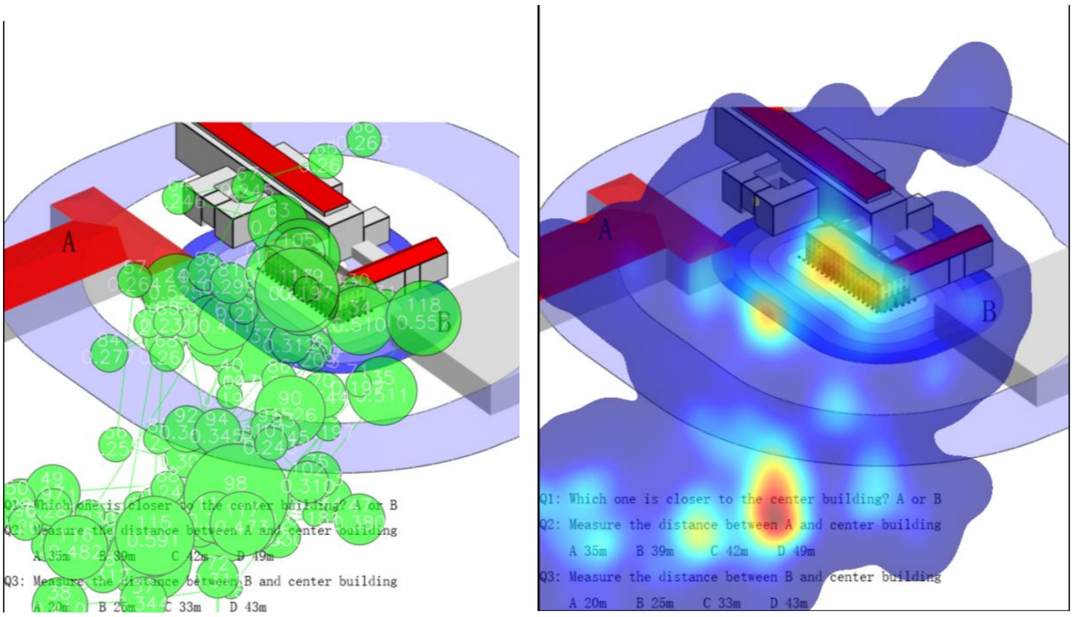
When discussing the eye tracker tracking analysis experiment, fixations and gaze point are the most basic output content of eye tracker analysis. Gaze point will show what your eyes are looking at. The eye tracker collects data at 60Hz, according to common sense, therefore, a 60 independent gaze points would be got per second. When a series of gaze points are quite close (in terms of time or space), these gaze points will form a fixation, indicating that your eyes have been locked on an object for a certain period of time. For visual attention, fixation is a very good measurement method.

Heatmap is a visualization method that shows the approximate distribution of gaze points. They are usually displayed as color gradients in pictures. Compared with fixation map, heatmap is an intuitive method to quickly discover what is the most attractive in the image and which objects are more attractive than other objects.

Heatmaps can be compared across single respondents as well as groups of participants, which can be helpful in understanding how different populations might view a stimulus in alternative ways.

In this experiment, each 3D map was displayed for 45 seconds. In the next part, an analysis will be made on these fixation maps and heatmaps task by task.

4.1.1 Fixation map and Heatmap of Group1 Task 1

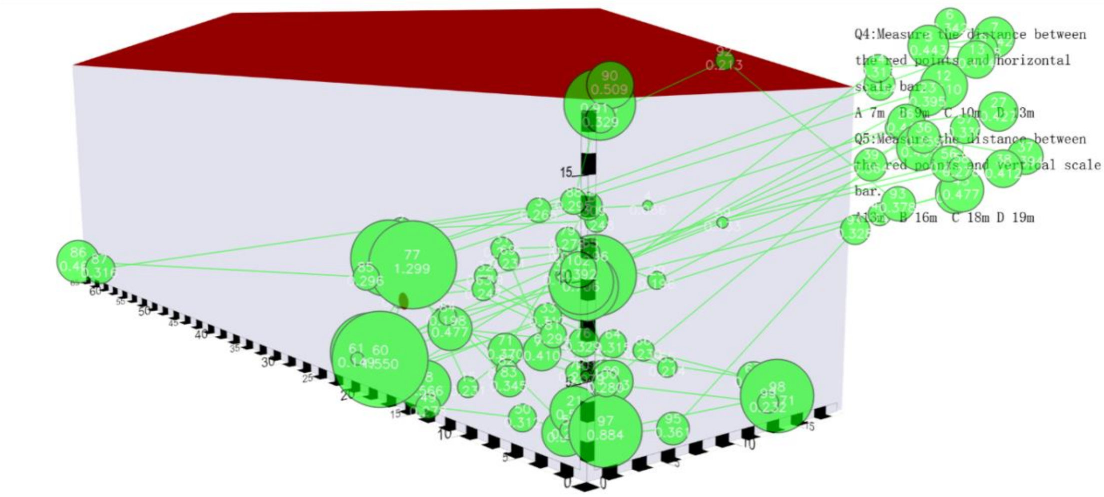


(a) (b)

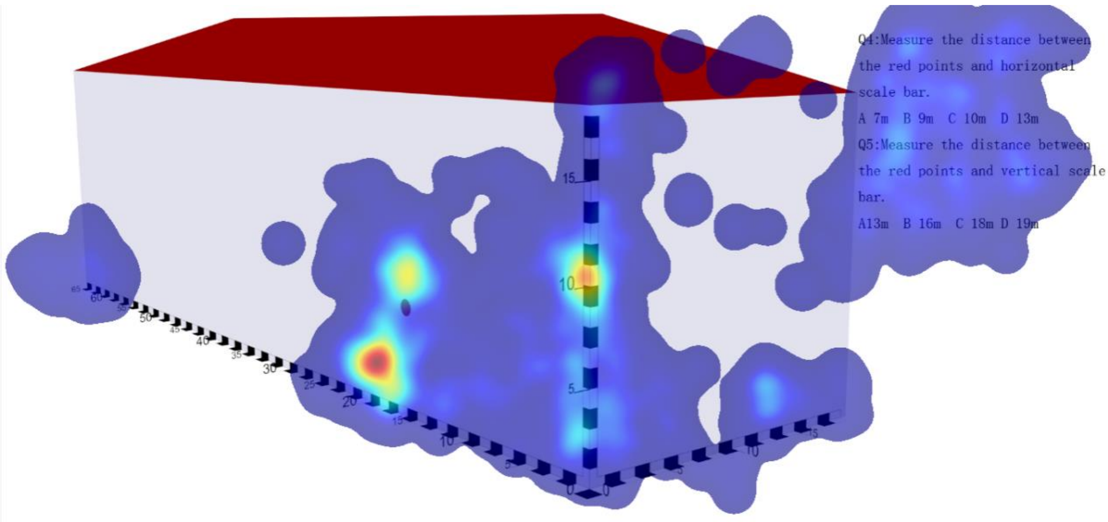
Figure 15. Fixation Map (a) and Heatmap (b) of Group1 Task 1

As shown in Figure15, from the fixation map and heatmap in Task 1, it’s obvious that the attention of participants is mainly concentrated in three areas, one is the description part of the task, one is on the building in the center of the map, and the other is on the buffer zone. AOI Option did not get too much attention. This may be because it is more critical for this participant to read the contents of the AOI task carefully for the solution of this problem. He can use the buffer zone tool to estimate the distance from A to the central building and from B to the central building. At the end, he can quickly choose one of the four options that is closest to the correct one in his mind.

4.1.2 Fixation map and Heatmap of Group1 Task 2



(a)

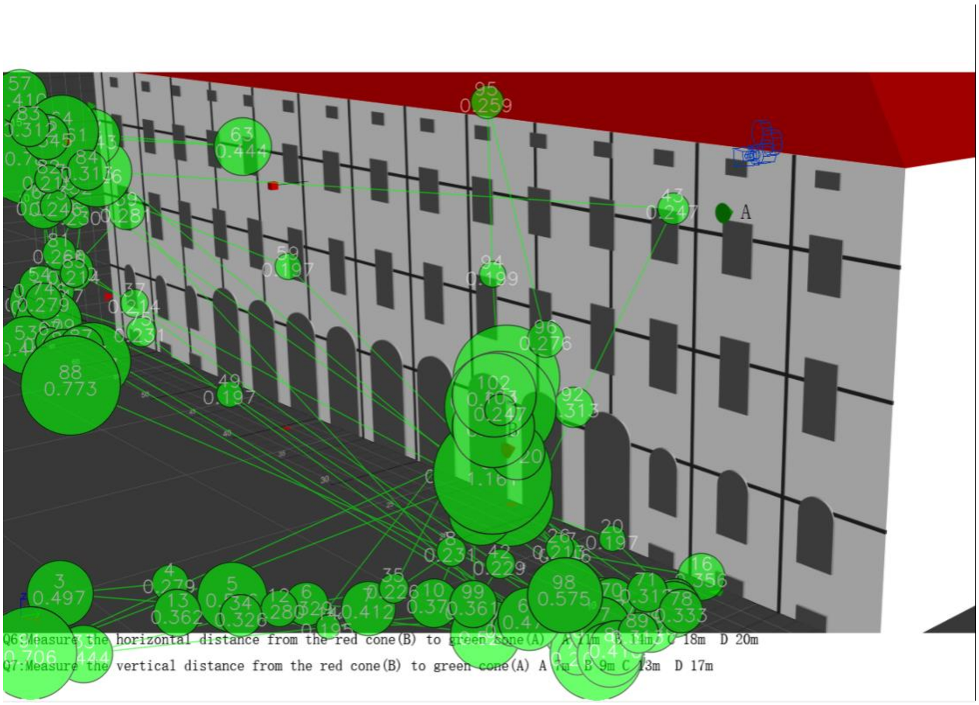


(b)

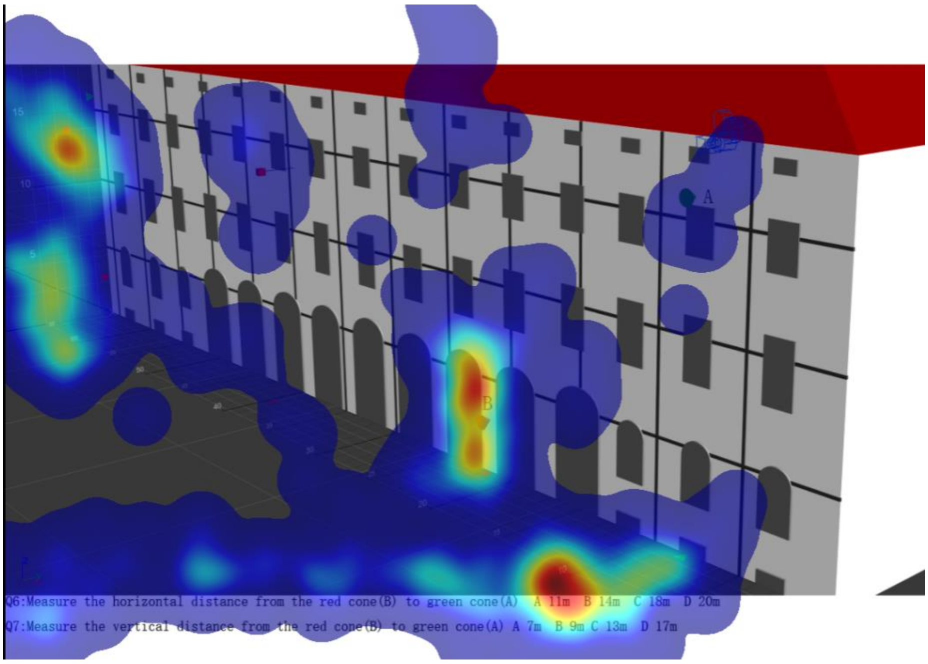
Figure 16. Fixation Map (a) and Heatmap (b) of Group1 Task 2

As shown in Figure 16, from the fixation map and heatmap in Task 2, it’s obvious that the attention of the participants is mainly attracted by the provided tool and the scale bar, which appears as two red dots in the heatmap. In addition, the AOI object attracts the participants' attention, which is represented by yellow dots. The difference between the heatmap of Task 2 and the heatmap of task 1 is that the experiment participants have significantly less time to read the topic, which is the AOI Task area. The reason may be that they are not familiar with the entire process at Task 1 and buffer zone and they read the topic description carefully. When they got to Task 2, they was already familiar with the experiment process, and the scale bar is more common than the buffer zone, so it can reduce the time required to read the topic description. The last point that interests us more is that the end of the horizontal scale bar usually turns blue. Participants in the performance experiment usually estimate how long and wide the entire object is, so as to establish an overall impression of qualified objects, and then estimate the distance from a point on the object to the scale bar.

4.1.3 Fixation map and Heatmap of Group1 Task 3



(a)

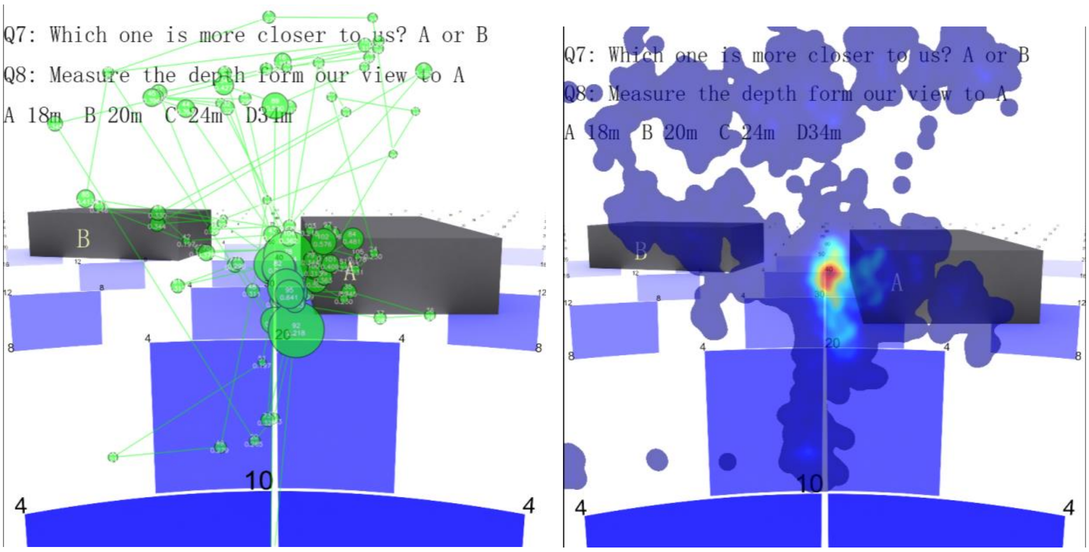


(b)

Figure 17. Fixation Map (a) and Heatmap (b) of Group1 Task 3

As shown in Figure17, similar to Task 2, in the fixation and heatmap of Task 3, the participants in the experiment just quickly browsed the AOI Task. In the Heatmap of Task 3, the three red dots represent the places where the participants are most focused. Two of them are on the provided grids, and the other is on target B. There is also a yellow dot on the AOI Tool. This means that most attention of the participants in the experiment in Task 3 focused on the provided tool Grids.

4.1.4 Fixation map and Heatmap of Group1 Task 4

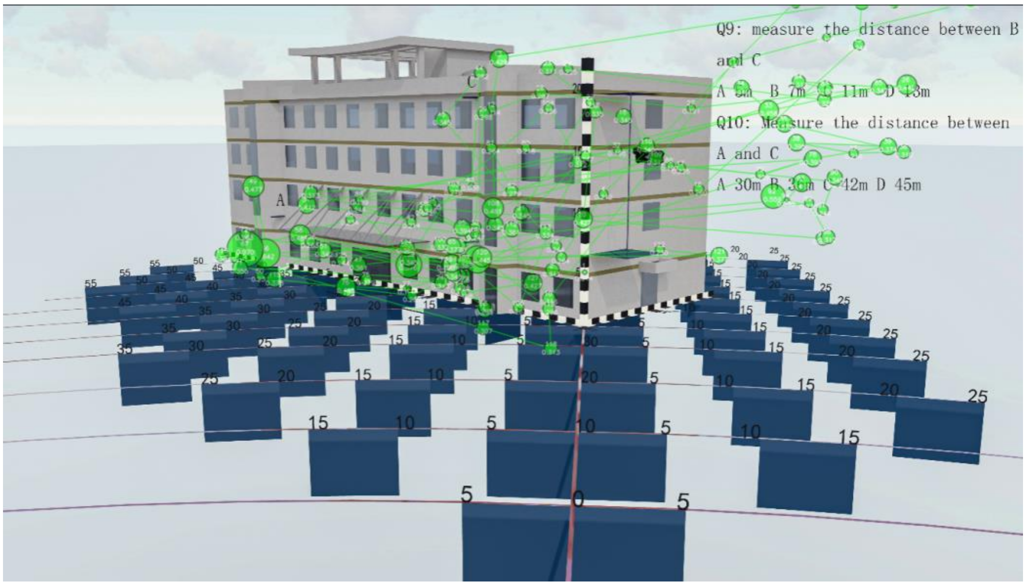


(a) (b)

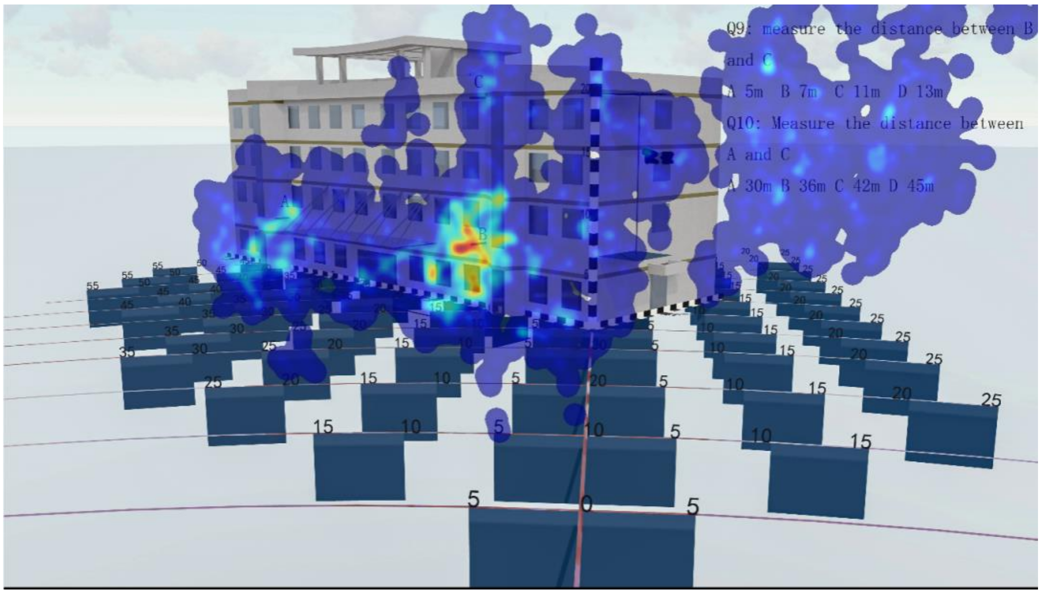
Figure 18. Fixation Map(a) and Heatmap(b) of Group1 Task 4

Same as the previous Task, in Task 4, the experimental participants also quickly browsed the AOI Task. However, in Task 4, the experimental participants did not separate part of the attention on the AOI object as before. They put most of their attention on the provided Distance Fan. As shown in Figure 18(b), there is only one red dot in the Heatmap of Task 4, and it contains the numbers '30' and '40' on Distance Fans. This shows that in this task, numbers are the key point in solving the task.

4.1.5 Fixation map and Heatmap of Group1 Task 5



(a)

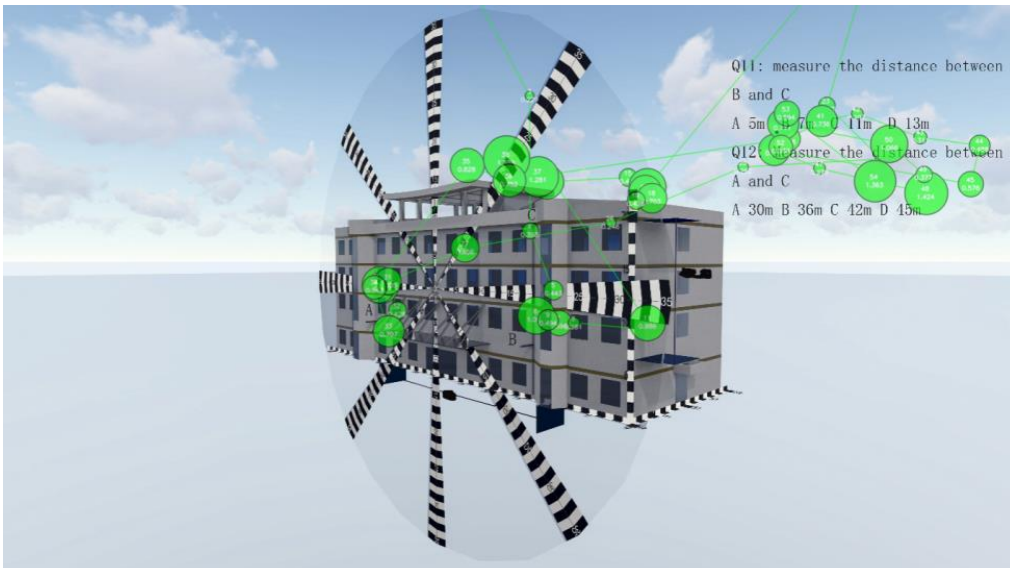


(b)

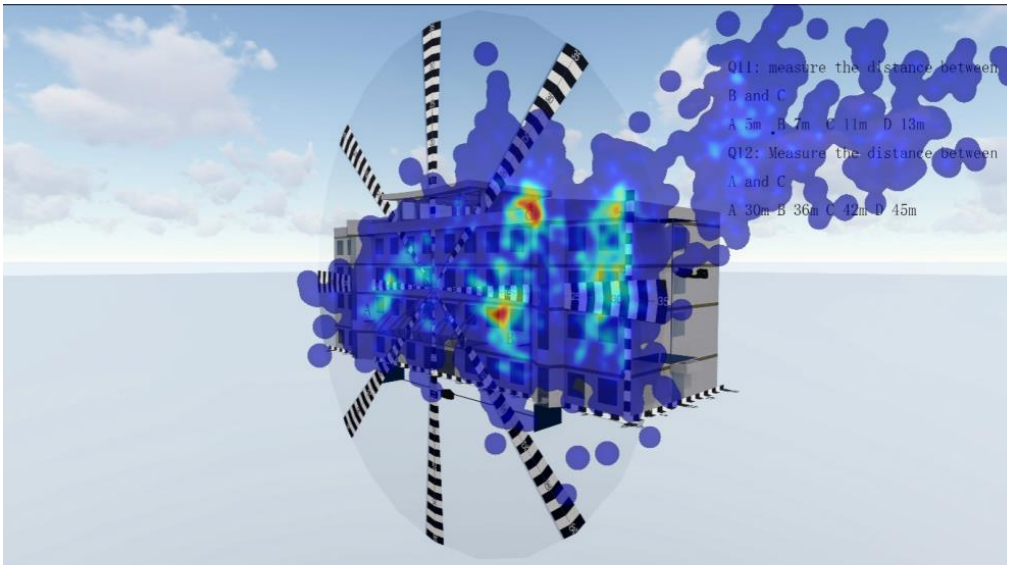
Figure 19. Fixation Map (a) and Heatmap (b) of Group1 Task 5

Compared with the previous Task, Task 5 is more difficult. Participants in the experiment not only have to use tools to calculate the horizontal or vertical distance like distance between “B” and “C”, they also have to measure the distance between the “A” and “C” points. It can be seen from the Figure 19 (b) that the red dots are mainly concentrated in the “B” area.

4.1.6 Fixation map and Heatmap of Group2 Task 1



(a)



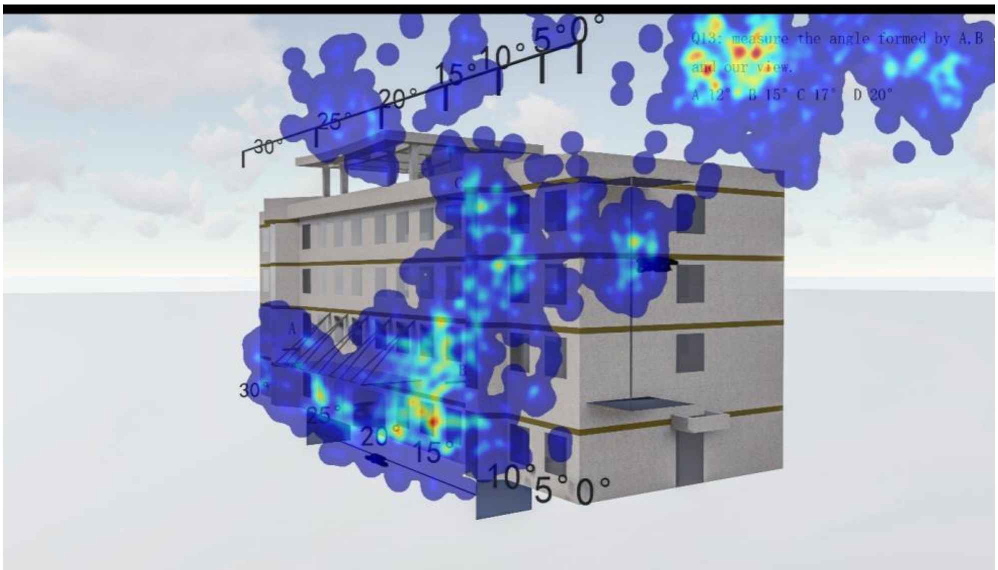
(b)

Figure 20. Fixation Map (a) and Heatmap (b) of Group2 Task 1

The Group 2 Task 1 is a comparison task of Group 1 Task 5. The problems that the two tasks need to solve are exactly the same, but the provided tools are completely different. In the Figure 20 (b), it can be found that the difference from group 1 Task 5 is that the two red areas contain points “B” and “C”, and the other yellow area contains point “A”, which means that when they are using the tools provided by this group, the participants of the experiment will divide their attention evenly among the three points “A”, “B” and “C”.

4.1.7 Fixation map and Heatmap of Group2 Task 2

(a)



(b)

Figure 21. Fixation Map (a) and Heatmap (b) of Group2 Task 2

From Figure 21 (b), as a new tool that participants are not familiar with, when participants in the experiment faced this task, a red area appeared in the AOI Question, which means that they want to understand what the task is to solve by reading the task description carefully.

4.2 Successful Rate

For judging the effectiveness of measurement tools in 3D maps, the successful rate of each question is the most intuitive performance. When in a task, a high successful rate means that the measurement tool in the figure has played a role. If the accuracy rate is low, it means that the tool is ineffective or has limited effects.

4.2.1 Successful Rate in Group 1

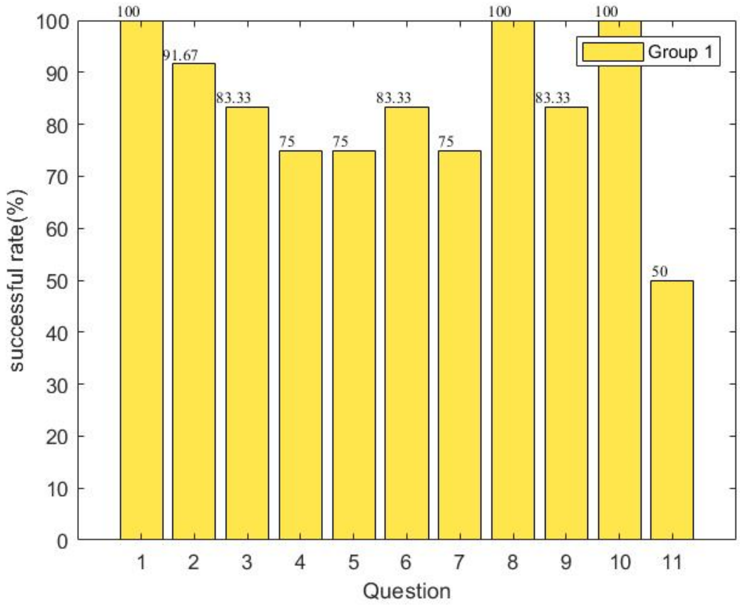


Figure 22. The Successful Rate for Each Question in Group 1

The Successful Rate of the 11 Questions in Group 1 is shown in Figure 22. From the histogram, it's obvious that except Q11, the Successful Rate of all other 10 Questions is above 75%. Unfortunately, only Q11's Successful Rate is 50%. This shows that the measurement tools in the Task 1-4 map are all effective. They can have a positive effect when the experiment participants browse the map and help the participants measure the distance in the 3D map and assess the depth. It also can be seen that Q10 and Q11 use the same tools, but the Successful Rate is very different. This is because the combination of Distance Fan and Scale Bar is effective when measuring the distance between the horizontal or vertical two points of a 3D map, but in the face of the diagonal distance, the combination of these two tools becomes powerless and can only rely on experiments participants to measure the horizontal and vertical distance and calculate it by themselves, which is hard in 45 seconds.

With the consideration of the difficulty of Question, there are some new discoveries. Q1 and Q8 are the two least difficult questions. Almost all experiment participants answered these two questions correctly. The difficulty of Q2, Q3, Q4, Q5, and Q9 is higher than that of Q1 and Q8, so the correct rate of experiment participants also decreased when facing these problems. The reason why the Successful Rate of Q4 and Q5 is lower than that of Q2 and Q3 is that the scenario of Task 3 is more complicated than that of Task 2, so the cognition of experimental participants will be more difficult. The most difficult questions, namely Q6, Q7, Q10, and Q11, the accuracy rate is a bit lower than the previous group. Therefore, the difficulty of the question has a great influence on the correct rate of the experimental participants. The more difficult the experimental problem is, the more complex the scene is, the lower the Successful Rate of the experimental participants will get, and the higher the requirements for the tool we designed.

4.2.2 Successful Rate in Group 2

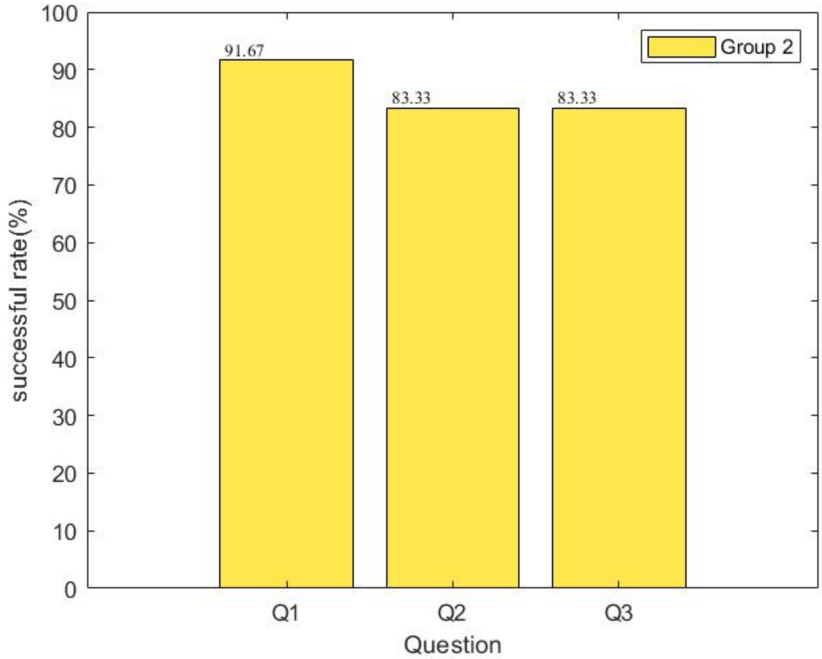


Figure 23. The Successful Rate for Each Question in Group 2

Group 2 contains two newly designed tools, so Group 2 appears as a comparison group of Group 1. Task 1 of Group 2 and Task 5 of Group 1 use exactly the same scenario and the same difficulty. In this way, the level of Successful Rate can prove which of the two sets of 3D map measurement tools is more effective. When facing the horizontal or vertical distance between two points in the 3D map, the Successful Rate of Group 2 Task 1 Question 1 also reached 91.67%. Although it is lower than the Successful Rate of Group 1 Task 5 Q11, it can also prove the effectiveness of the new tool in the face of this Question. A few percentage points lower may be caused by the added tool, which makes the scene more complicated, so there will be misjudgment. From Figure 23, the Successful Rate of Group 2 Task 1 Question 2 reached 83.33%, which is much higher than the 50% of the controlled trial. This shows that the new designed tool has a better effect when facing the diagonal distance. Participants in the trial can find the corresponding point from the new tool to measure the distance. The Successful Rate of Group 2 Task 2 Q 3 also reached 83.33%. This shows that the designed angle calculator is effective for angle measurement in 3D maps. In the future augmented reality, it can be believed that this angle calculator will be applied to augmented reality glasses to help people get more information.

4.3 Dwell and Transition

In order to better improve the effect of the measurement tools in the 3D map, and to better develop other 3D map measurement tools, it’s necessary to extract the recognition mode of each participant in the task from each task, and compare the correct recognition mode and wrong recognition mode. For each task, the fixation sequence of all experiment participants shall be visualized into a sequence chart. In the sequence chart, all colors correspond to the AOI area. For the fact that each map will be displayed for 45s in each different task, the sequence chart we see has the same length and can be easily used to compare the differences between them. The transition probability of successful participants and failed participants would also be visualized. In this way, through these two visual data, an analysis could be made for the recognition patterns of successful participants and failed participants in the experiment.

For Group1 Task1 “Which one is closer to the center building?(B)” and “Measurement the distance between A and center building.(C 42m)” “Measure the distance between B and center building(C 33m)”, the participants need to find the distance of A and B. In order to solve this task, the best recognition mode shall be (1) carefully read the AOI Question part, (2) search for AOI Object in the map to locate Object A and B, (3) measure with the tool Buffer zone provided in the map and, and (4) transfer during the period Go to the AOI Option section to compare and choose the correct answer that is closest to your own feeling. As shown in Figure 24, most of the experiment participants spent a lot of time checking the AOI Question and AOI Object parts. However, the failed participants spent more time on the AOI Option than the successful participants. However, the AOI Option part has no positive effects on solving Task 1, which leads to a difference in the correct answer rate of participants.

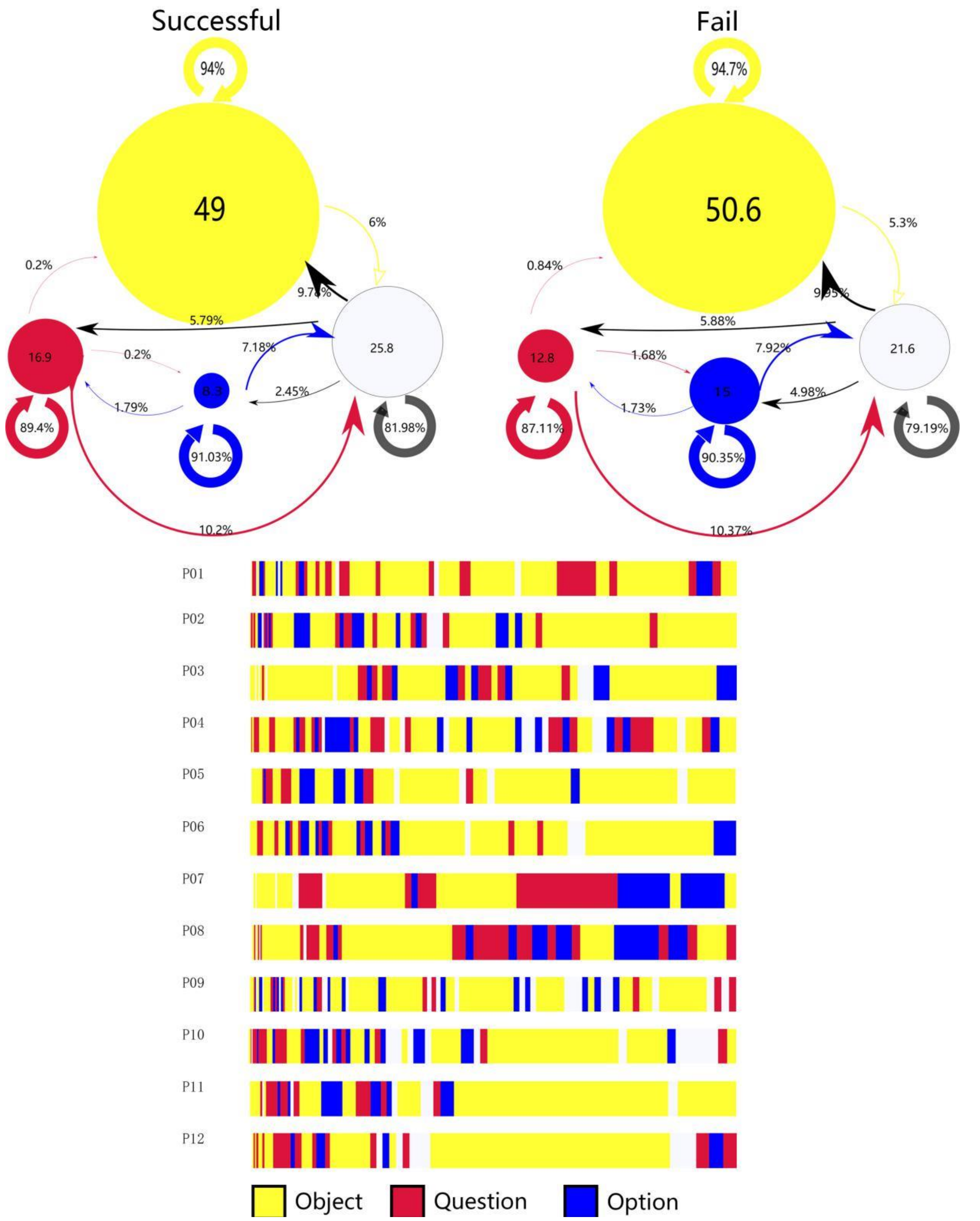


Figure 24.The Visualization of Search Strategies of Group 1 Task 1: the dwell and transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

For Group1 Task2 “Measure the distance between the red point and horizontal scale bar (A 7m)” and “Measure the distance between the red point and vertical scale bar (B 16m)”, the best solution shall be (1) carefully read the problem description in the AOI Question, (2) locate the position of the red dot in the map AOI Object, (3) find the projection point corresponding to the red dot in the scale bar, and (4) go back to the AOI Option section to find the answer. As shown in Figure 25, when solving this problem, the difference between failed experiment participants and successful experiment participants is that the failed experiment participants spend too much time in the AOI Question part and more time in the AOI NULL part. This results in less time for them to locate the red dot and the projection point of the scale bar. The projection point cannot be accurately positioned, so they failed.

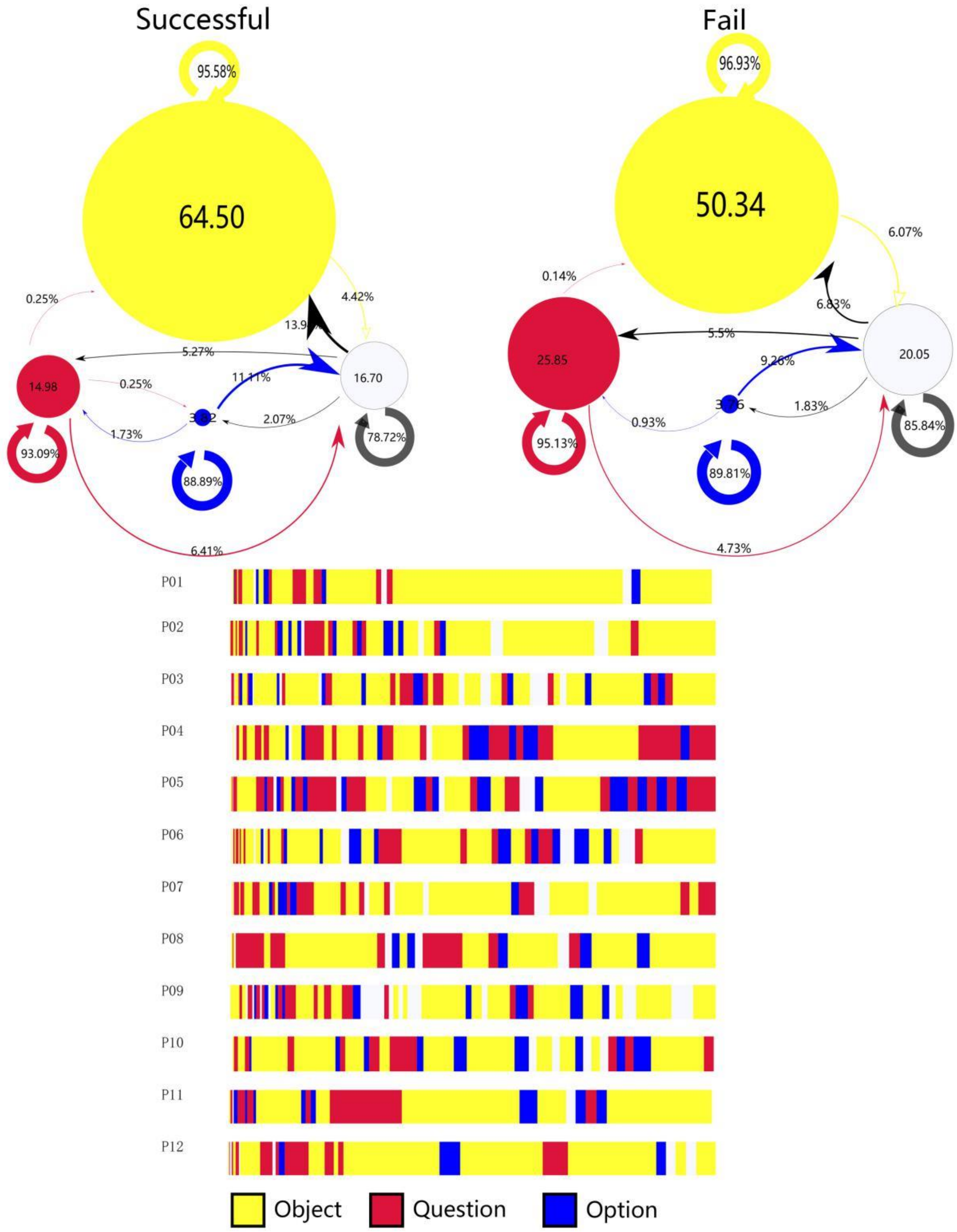


Figure 25.The Visualization of Search Strategies of Group 1 Task 2: the dwell and transition chart of the successful group (upper left) The dwell and transition chart of the successful group (upper right) The sequence chart (lower one)

For Group1 Task 3 “Measure the horizontal distance between B and A (B 14m)” and “Measure the vertical distance between B and A (13m)”, the most powerful solution shall be (1) carefully read the problem description in the AOI Question, (2) use the marker to locate A and B and their projected point on grids, and (3) back to AOI Option part to answer the question. As shown in Figure 26, Participants who failed in the experiment almost ignored the AOI Option part, which means that they only glanced at the option before making a choice, and even when they chose, they did not know whether it was the option they wanted to choose. However, this experimental design also has shortcomings. Because the software cannot set the polygon interest area, which leads us to face the AOI Tool interest area that should have appeared in Task 3, therefore, there are many AOI NULL. This will affect some experimental results.

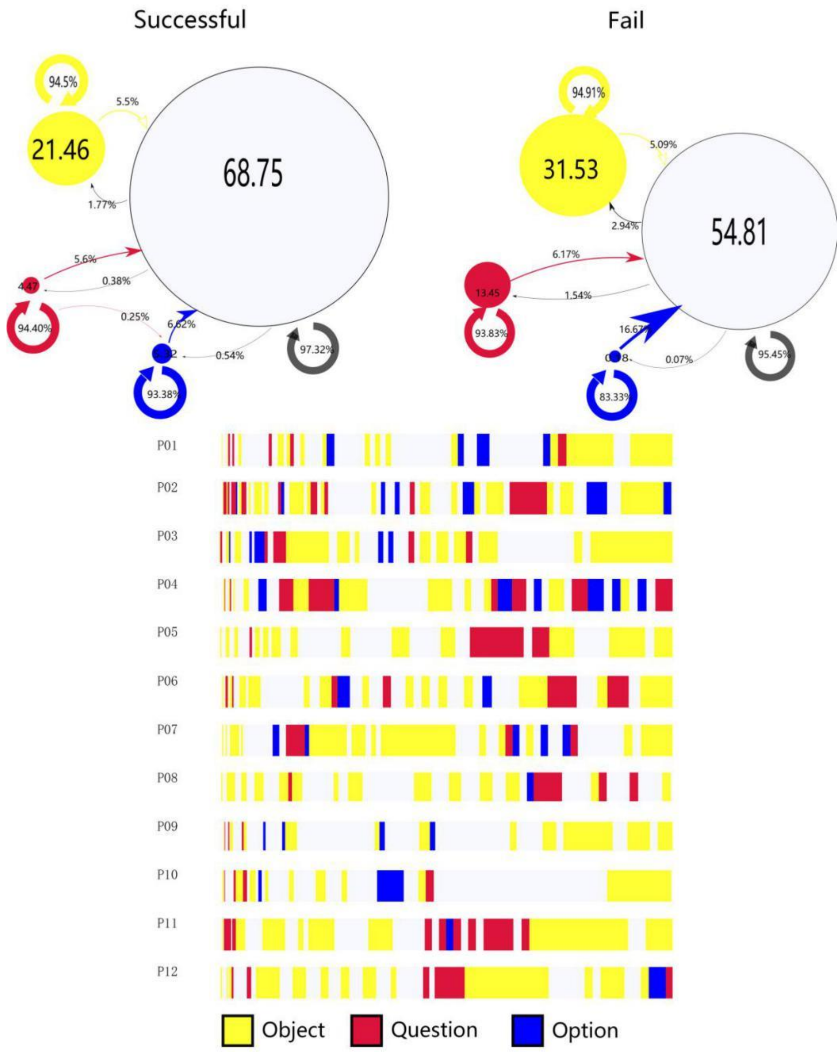


Figure 26.The Visualization of Search Strategies of Group 1 Task 3: the dwell and transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

For Group1 Task4 “Which one is closer to us? (A)” and “Measure the depth from our view to A(C 34m)”, the best solution shall be (1) read the task description in AOI Question carefully, (2) locate A and B in AOI object, (3) estimate the depth of A and B using the tool in AOI Tool, and (4) back to AOI option part to answer the question. Because AOI Object and AOI Tool overlap in part, when the data is finally generated, the overlapped part will be named AOI Object-Tool in the data. As shown in Figure 27, it can be seen that successful experiment participants spent a lot more time in AOI Tool and AOI Object-Tool than failed participants. And among the successful participants, they spend less time in the AOI Question section, which means that they have gone through the previous tasks and are more familiar with the task description of this experiment, which means that our tool is useful when measuring depth on 3D maps. Using this tool can significantly improve the accuracy of Task 4.

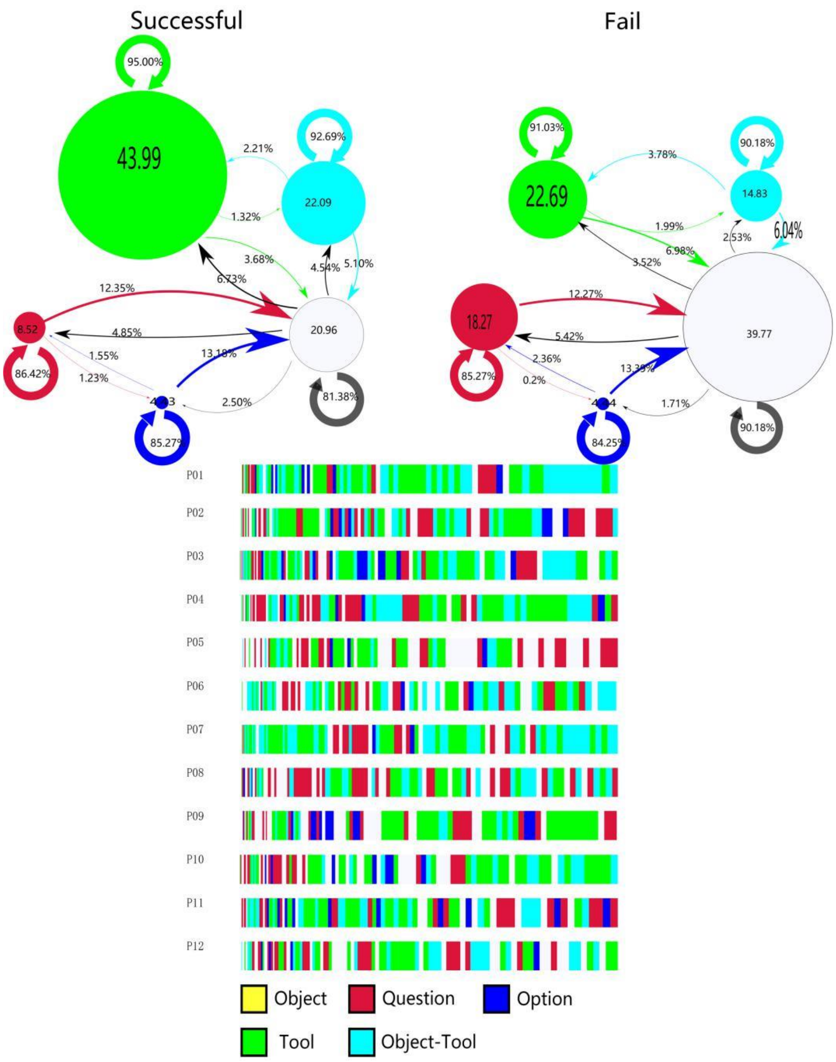


Figure 27.The Visualization of Search Strategies of Group 1 Task 4: the dwell and transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

For Group1 Task 5 “Measure the distance between B and C (D 13m)” and “Measure the distance between A and C (B 36m)”, the best solution shall be (1) read the task description in AOI Question, (2) locate Point A, Point B and Point C, (3) find the corresponding projection point on the tool and (4) back to AOI Option part to answer the question. Obviously, as the control group of Group 2 Task1, the last question is difficult for all participants to answer. Faced with the oblique distance between AC, because the corresponding projection point cannot be found in the corresponding tool, the experimental participants can only use the tool to measure the distance between AB and BC, and then use the Pythagorean theorem to calculate the distance between AC. Completing within 45 seconds is obviously an unlikely task. But because of the option setting for the last question, experiment participants can eliminate the option by the distance between AB and BC, and then choose the closest one. As shown in Figure 28, it can be seen that successful participants spend more time in AOI Tool and AOI Object-Tool. Finally, when choosing the answers, they also spent more time thinking about which choices should be excluded in AOI Option.

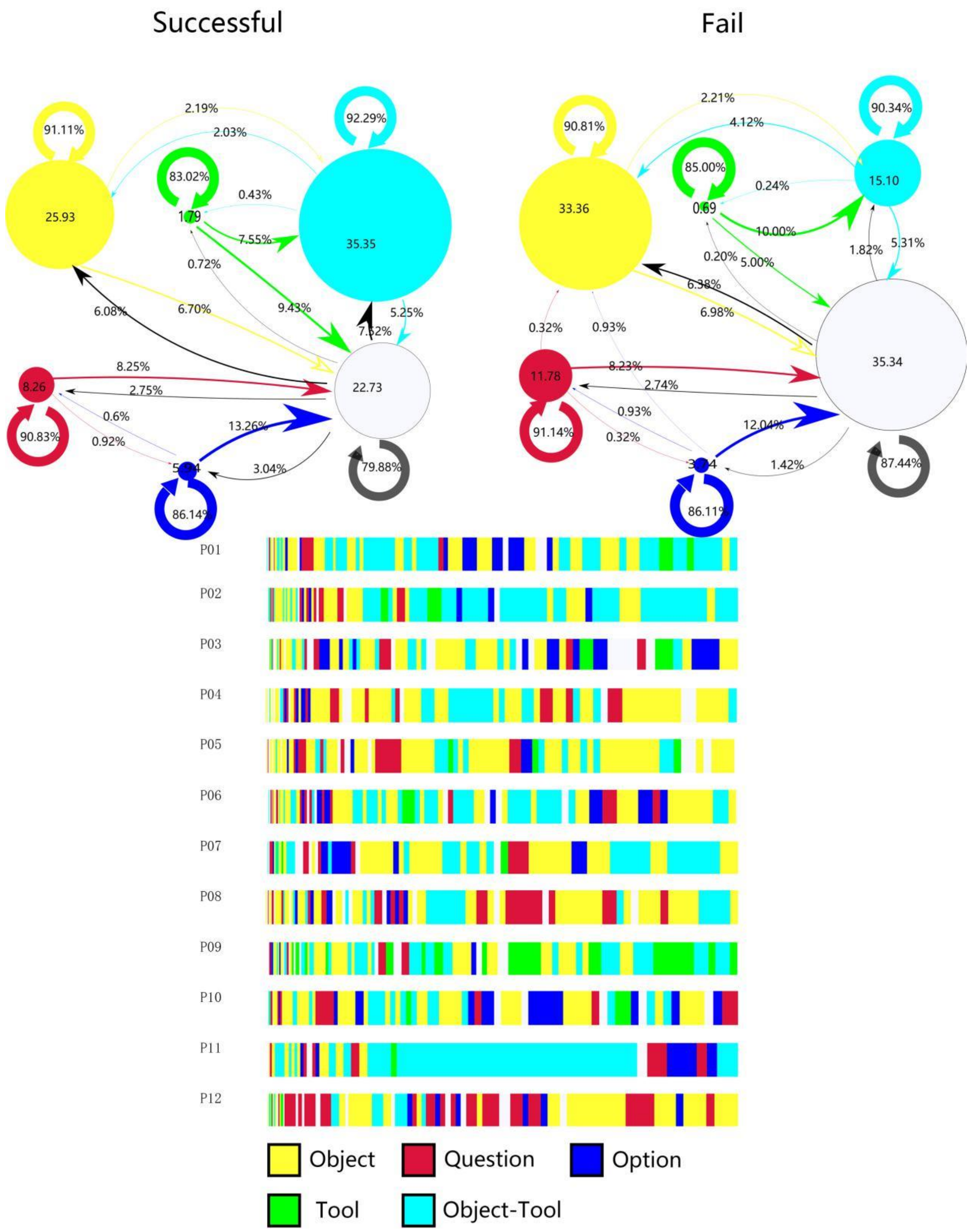


Figure 28. The Visualization of Search Strategies of Group 1 Task 5: the dwell and transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

As the control group of Group1 Task5, except for the different tools on the map, the two tasks contain the same problems, and the best way to identify them shall also be the same. Unlike Group1 Task5, when facing the oblique distance between A and C, the participants of the experiment can find the approximate projection points from the newly designed measurement tool to estimate the distance between A and C. As shown in Figure 29, it can be seen that successful experiment participants spend more time in AOI Tool and AOI Object-Tool, and less time in AOI Option. This is because there are approximate projection points to be relied on. Participants no longer need to use AOI Option to eliminate wrong answers, and only need to spend more time looking for approximate projection points.

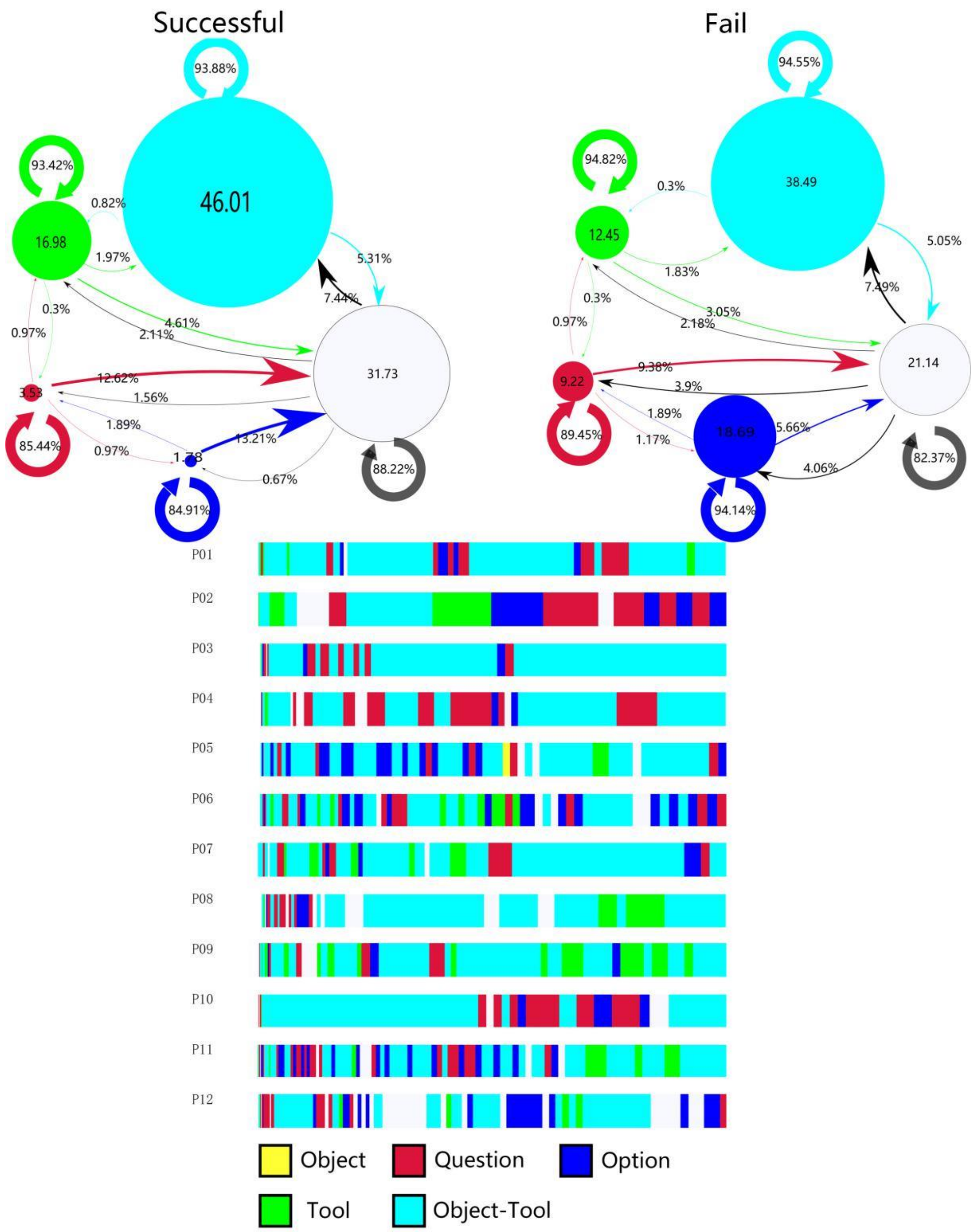


Figure 29. The Visualization of Search Strategies of Group 2 Task 1: the dwell and

transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

For Group 2 Task 2 “Measure the distance formed by A, B and our view(B 15°)”, the best solution shall be (1) read the task description in AOI Question, (2) locate Point A and Point B in AOI Object, (3) find the projection point on the tool, and (4) back to the AOI Option part to answer the question. As shown in Figure 30, successful participants looked at the AOI Object-Tool area more than failed participants, as a result, there is a light blue part. In addition, another important point, which is not obvious in Figure X. There are two yellow thin lines from AOI Object to AOI Tool and AOI Object-Tool, accounting for only 0.08%. These two lines are very important, representing that successful participants are looking for corresponding points of Point A and Point B on the given tool, which also leads to the correctness of participants' answers in this task.

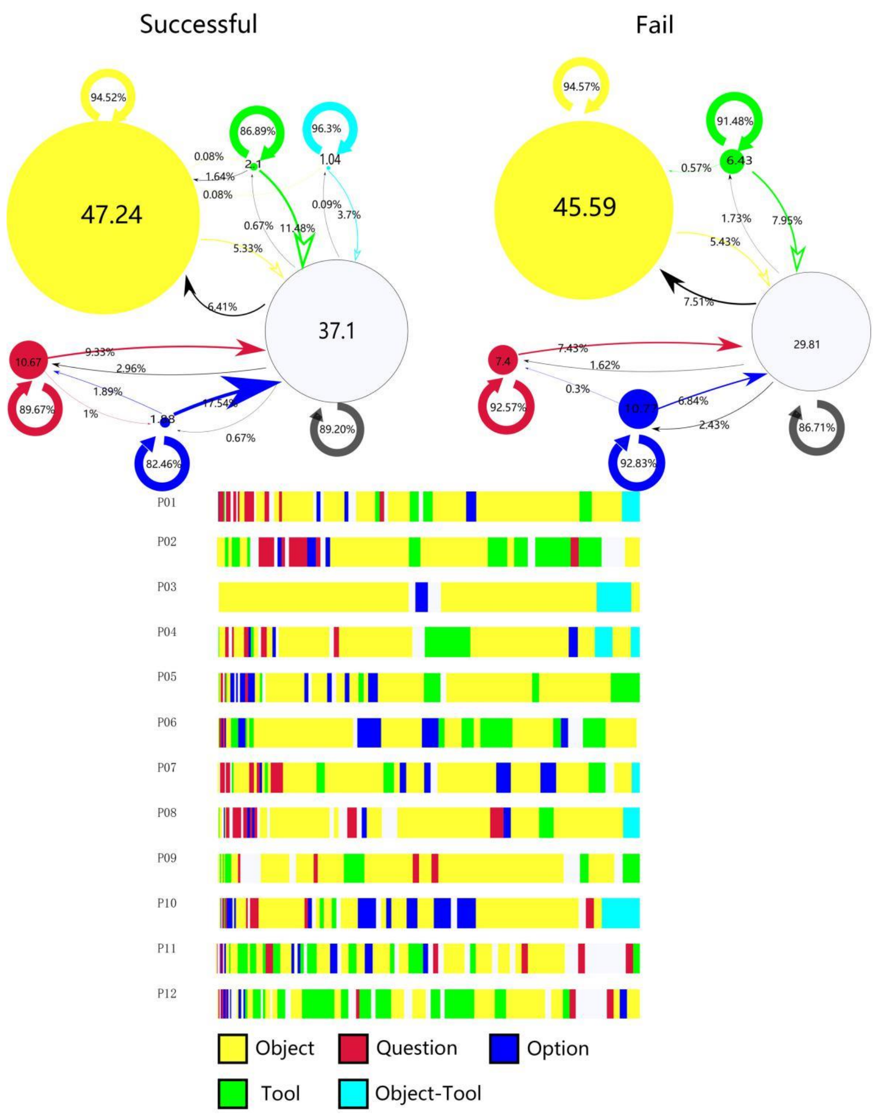


Figure 30. The Visualization of Search Strategies of Group 1 Task 5: the dwell and

transition chart of the successful group (upper left) the dwell and transition chart of the successful group (upper right) the sequence chart (lower one)

4.4 Feedback

In this section, the 3D map measurement tool will be evaluated through the interview with the experiment participants after the experiment. In the following, the discussion shall focus on the participant's evaluation of the 3D map measurement tool we designed.

In Group 1, the participants rated on average 4.08 (1-5 from less to more confident) on the confidence of their answers, and 3.95 (1-5 from hard to easy to use) on the usability of the measuring tool. Therefore we can see that the overall results in Group 1 were very positive. And for each tasks in Group 1, the participants rated the buffer zone in Task 1 on average 4.16 (1-5 from not useful at all to very useful), rated the scale bar in Task 2 on average 4.16 (1-5 from not useful at all to very useful), rated the grids in Task 3 on 4.08, rated the distance fan in Task 4 on 4 (1-5 from not useful at all to very useful), rated the combined tool in Task 5 on 3.584 (1-5 from not useful at all to very useful). There are 2 reasons for this results: the first one is that the tasks become more and more complex, and the second one is that as the control group of Group 2 Task1, the participants should meet some problems when completing Group 1 Task 5.

In Group 2, the participants rated on average 3.58 (1-5 from less to more confident) on the confidence of their answers, and 3.16 (1-5 from hard to easy to use) on the usability of the measuring tool. The confidence in Group 2 was a little weaker than that in Group 1. The reason relies on the complex Tasks and measuring tools. And for each tasks in Group 2, the participants rated the tool in Task 1 on average 4.25 (1-5 from not useful at all to very useful), rated the scale bar in Task 2 on average 3.5 (1-5 from not useful at all to very useful).

We asked the participants of the experiment, in the course of this experiment, which elements were difficult for them to understand or easily caused errors in their understanding and whether the tools are helpful when completing the tasks. The positive feedback is summarized in Table 3. The negative feedback is summarized in the Table 4.

Table 3. Positive Elements from Feedback

Elements	Frequency
The buffer zone is helpful.	7
The scale bar is helpful.	10
The grid is helpful.	8
The distance fan is helpful	8
The circle like scale bar is helpful	7
The angle calculator is helpful.	6

Table 4. Negative Elements from Feedback

Elements	Frequency
The participants are not familiar with distance fan.	1
Time limitation is not necessary.	2
Scale bar is far from the object.	1
Numbers should be clearer.	5
The participants are not familiar with the tool in Group2 Task2.	3
Participants need more text explanation.	3

In summary, the measurement tools in 3D maps are effective. They can help experiment participants obtain distance information, depth information, and angle information from the map, which is undoubtedly a huge help in a virtual environment. When designing these tools, the colors of the tools should be kept as clear as possible, and the ruler numbers on the tools should be clear, which is very effective for participants to read 3D maps.

5. Discussion

In this part, the attention shall be paid to the strengths and weakness of 3D map measurement tools in obtaining 3D map information, as well as the shortcomings of this experiment.

As we all know, the measurement tools in 3D maps are used to help map readers to obtain various information in the map. The 3D map measurement tool is the bridge between the map reader and the 3D map. For the buffer zone in Group 1 Task1, a buffer zone of 10m is not accurate enough for map readers, and map readers can only guess the specific distance based on their own feelings. For the scale bar in Group 1 Task 2, this is undoubtedly the measurement tool that people come into contact with experience in daily life, no matter 3D or 3D map. However, the limitation of the scale bar is great. When the point to be measured is far away from the scale bar, due to the perspective relationship in the 3D map, when the map readers without training are looking for the projection point on the scale bar, errors often occur, and this is where improvement is needed. For the Grid in Group2 Task 3, the Grid may block the map and cause loss of information, especially when the grid is dense. For Distance Fan in Group 1 Task 4, it is more suitable to be applied to virtual reality maps. This tool is more suitable for experienced and trained users. For users who come into contact with it for the first time, the effect is relatively small. For the combined tool of Group 1 Task5, it can help map readers to collect the horizontal or vertical distances in the 3D map, but when facing the oblique distance between two points on the plane, it becomes powerless. For the circle like scale bar of Group 2 Task 2, it can help map readers to deal with the oblique distance between two points. However, since this tool is large and occludes the 3D map, it will also cause the loss of information. It and the combined tool in Group 1 Task 5 have their own advantages and disadvantages. Map readers can choose the right tool according to their own situation. For the Angle calculator of Group 2 Task 2, if the participants of the experiment have played a shooting game similar to FPS before, they will be familiar with this tool and the application will be handy. However, when experiment participants do not have similar experience, it will take more time to explain to them how to use this tool. Similarly, this tool is more suitable for use in the augmented reality world.

When evaluating the measurement tools in the 3D map designed in this experiment, a combination of interview and eye tracker experiments is introduced. In this way, it is more scientific to verify the results of the interview through the scientific data of the eye tracker. The results of the experiment show that the 3D map measurement tool we designed can help map readers to obtain the information in the 3D map.

However, this experiment also has shortcomings. Because the software used in this experiment cannot generate polygonal AOIs on the map, the first three tasks of Group 1 could not be added with AOI Tool, which may prevent us from discovering more content when analyzing experimental results. In addition, due to the COVID-19 lockdown, only 24 people participated in this experiment. In the future, the research focus shall be made on expanding the sample size of the experiment and more detailed analysis of more data.

6. Conclusion

3D map surveying tools build a bridge between map users and map information. Through the understanding of collecting information and the knowledge of cartography, the effectiveness of the existing 3D map measurement tools are verified, and new 3D map measurement tools suitable for different fields are designed.
In this research, in order to verify the effectiveness of the measurement tools in the 3D map, an experiment that includes eye tracking experiments and interviews is introduced. An analysis is made of the data obtained from the eye tracking experiment in terms of fixation, success rate and dwell and transition metrics. Moreover, the feedbacks given by the experiment participants is analyzed and these feedbacks into positive elements and negative elements is summarized in the table. The results of eye movement experiments and interviews verify the effectiveness of the measurement tools in 3D maps, and the newly designed 3D map measurement tools have their suitable application scenarios.

The future research shall focus on 4 main tasks. Firstly, design a software like SMI BeGaze[35] that can set the polygon AOI and regenerate the data. Secondly, improve the 3D map measurement tool from the feedback of the experimental participants to make the numbers clearer and the description more complete. Thirdly, apply these tools to different 3D maps and conduct more experiments. Finally, design methods with more visualization to explore the eye tracker experimental data and explore more possibilities of the data.

References

1. Rayner K. Cognitive Control of Eye Movements. *Psychol Bull*. 1998;124(3):372-422. http://content.apa.org/journals/bul/124/3/372%5Cnpapers2://publication/uuid/EE315426-1E21-4F51-9908-80F30C62CDD4%0Ahttp://doi.apa.org/getdoi.cfm?doi=10.1037/0096-1523.22.5.1188.
2. Holmqvist K, Nyström M, Andersson R, Dewhurst R, Jarodzka H, Weijer J van de. Eye Tracking A Comprehensive Guide to Methods and Measures. *J Chem Inf Model*. 2013;53(9):1689-1699.
3. Poole A, Ball LJ. Eye Tracking in Human-Computer Interaction and Usability Research: Current Status and Future Prospects. *United Kingdom Psychol Dep Lancaster Univ*. 2005:211-219. doi:10.4018/978-1-59140-562-7
4. Duchowski AT. *Eye Tracking Methodology*.; 2017. doi:10.1007/978-3-319-57883-5
5. Schindler M, Lilienthal AJ. Domain-specific interpretation of eye tracking data: towards a refined use of the eye-mind hypothesis for the field of geometry. *Educ Stud Math*. 2019;101(1):123-139. doi:10.1007/s10649-019-9878-z
6. Lee Y, Shin C, Plopski A, et al. Estimating Gaze Depth Using Multi-Layer Perceptron. *Proc - 2017 Int Symp Ubiquitous Virtual Reality, ISUVR 2017*. 2017:26-29. doi:10.1109/ISUVR.2017.13
7. Wade NJ. Pioneers of eye movement research. *Iperception*. 2010;1(2):33-68. doi:10.1068/i0389
8. Liversedge. Liversedge (2000) Saccadic eye movements and cognition. 2000;4(1):6-14.
9. Zugal S, Pinggera J. Low – Cost Eye – Trackers : Useful for Information Systems Research ? 2014:159-170.
10. Mayer RE. Unique contributions of eye-tracking research to the study of learning with graphics. *Learn Instr*. 2010;20(2):167-171. doi:10.1016/j.learninstruc.2009.02.012
11. Kulhavy RW, Stock WA. How cognitive maps are learned and remembered. *Ann Assoc Am Geogr*. 1996;86(1):123-145. doi:10.1111/j.1467-8306.1996.tb01748.x
12. Kiefer P, Giannopoulos I, Raubal M. Where am i? Investigating map matching during self-localization with mobile eye tracking in an urban environment. *Trans GIS*. 2014;18(5):660-686. doi:10.1111/tgis.12067
13. Kiefer P, Giannopoulos I, Raubal M, Duchowski A. Eye tracking for spatial research: Cognition, computation, challenges. *Spat Cogn Comput*. 2017;17(1-2):1-19. doi:10.1080/13875868.2016.1254634

14. Majaranta P, Bulling A. Eye Tracking and Eye-Based Human–Computer Interaction. 2014:39-65. doi:10.1007/978-1-4471-6392-3_3
15. Scholl BJ. Objects and attention: The state of the art. *Cognition*. 2001;80(1-2):1-46. doi:10.1016/S0010-0277(00)00152-9
16. Edsall R, Andrienko G, Andrienko N, Buttenfield BP. Interactive Maps For Exploring Spatial Data. *Man Geogr Inf Syst*. 2008:837-858. https://s3.amazonaws.com/academia.edu.documents/30369474/asprs08.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1512130816&Signature=U7XxZ3MfeX3A2PBDIv8%2FWoNmyt0%3D&response-content-disposition=inline%3B filename%3DInteractive_maps_for_exploring_spati.
17. Just MA, Carpenter PA. A theory of reading: From eye fixations to comprehension. *Psychol Rev*. 1980;87(4):329-354. doi:10.1037/0033-295X.87.4.329
18. Kuchinke L, Dickmann F, Edler D, Bordewieck M, Bestgen AK. The processing and integration of map elements during a recognition memory task is mirrored in eye-movement patterns. *J Environ Psychol*. 2016;47:213-222. doi:10.1016/j.jenvp.2016.07.002
19. Ghaoui C. Eye Mind Hypothesis. *Encycl Human-Computer Interact*. 2006.
20. Goldberg JH, Kotval XP. Computer interface evaluation using eye movements: Methods and constructs. *Int J Ind Ergon*. 1999;24(6):631-645. doi:10.1016/S0169-8141(98)00068-7
21. Zhang W, Liu H. Toward a Reliable Collection of Eye-Tracking Data for Image Quality Research: Challenges, Solutions, and Applications. *IEEE Trans Image Process*. 2017;26(5):2424-2437. doi:10.1109/TIP.2017.2681424
22. Mardanbegi D, Langlotz T, Gellersen H. Resolving target ambiguity in 3D gaze interaction through VOR depth estimation. *Conf Hum Factors Comput Syst - Proc*. 2019. doi:10.1145/3290605.3300842
23. Vogl J. Gazepoint 3 Eye Tracker Manual. University of South Dakota. 2014:33.
24. Vancouver BC. Gazepoint GP3 Quick Setup Instructions. (4293):3-5.
25. O'Brien S. Eye tracking in translation process research : methodological challenges and solutions. *Methodol Technol Innov Transl Process Res a Tribut to Arnt Lykke Jakobsen Copenhagen Stud Lang*. 2009:251-266.
26. Kumke H. Kartographische Anreicherung von Gebäudefassaden mit thermalen Bilddaten. 2011.
27. Ooms K, Maeyer P De, Fack V. Published as : Ooms , K ., De Maeyer , P ., & Fack , V ., 2015 . Listen to the map user : Listen to the Map User : Cognition , Memory , and Expertise. 2015;52(1):3-19.
28. Blascheck T, Kurzhals K, Raschke M, Burch M, Weiskopf D, Ertl T. State-of-the-Art of Visualization for Eye Tracking Data. *Eurographics Conf Vis*. 2014:1-20. doi:10.2312/eurovisstar.20141173
29. Zuo C, Ding L, Meng L. A feasibility study of map-based dashboard for spatiotemporal knowledge acquisition and analysis. *ISPRS Int J Geo-Information*. 2020;9(11):1-28. doi:10.3390/ijgi9110636

30. Kovari A, Katona J, Costescu C. Evaluation of Eye-Movement Metrics in a Software Debugging Task using GP3 Eye Tracker. *Acta Polytech Hungarica*. 2020;17(2):57-76. doi:10.12700/APH.17.2.2020.2.4
31. Kurzhals K, Hlawatsch M, Seeger C, Weiskopf D. Visual Analytics for Mobile Eye Tracking. *IEEE Trans Vis Comput Graph*. 2017;23(1):301-310. doi:10.1109/TVCG.2016.2598695
32. Kurzhals K, Heimerl F, Weiskopf D. ISeeCube: Visual analysis of gaze data for video. *Eye Track Res Appl Symp*. 2014:43-50. doi:10.1145/2578153.2578158
33. Yang CK, Wacharamanotham C. Alpscarf: Augmenting scarf plots for exploring temporal gaze patterns. *Conf Hum Factors Comput Syst - Proc*. 2018;2018-April(April). doi:10.1145/3170427.3188490
34. Tran VT, Fuhr N. Using eye-tracking with dynamic areas of interest for analyzing interactive information retrieval. *SIGIR'12 - Proc Int ACM SIGIR Conf Res Dev Inf Retr*. 2012:1165-1166. doi:10.1145/2348283.2348521
35. Stofer K, Che X. Comparing experts and novices on scaffolded data visualizations using eye-tracking. *J Eye Mov Res*. 2014;7(5):1-15. doi:10.16910/jemr.7.5.2