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Development of a Smart Learning Application in Multi-person Virtual Reality Using Biometric Measures of Neuroimaging, Eye Tracking, and Haptic Interactions

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Abstract

Non-text-based smart learning refers to technology-supported learning that uses non-text features (i.e. visualized information) and adapted learning materials based on the individual's needs. Fully immersive multi-person virtual reality (MVR) refers to humans located at different places wearing VR devices to join a single virtual room, a classroom with unlimited size, to learn from an instructor. The learning environment is poised to undergo a major reformation, and MVR will augment, and possibly replace, the traditional classroom learning environment. The ultimate purpose of this research and development of apps is to discover new smart learning methodologies within the MVR environment using nonintrusive multimodal analysis of physiological measures, including eye movement characteristics, haptic interactions, and brain activities. We provide the design concepts that were developed and implemented to create the MVR semantic network app. Furthermore, demonstration details are provided showcasing how we could leverage the MVR technology for education and training.

Keywords

Smart Learning, Multi-person Virtual Reality, Biometric Measures, Neuroimaging, Eye Tracking, Physiological Measures, Haptic interactions

Introduction

When students read a textbook, symbolic translations are needed to comprehend the materials. Comprehension is based on semantic memory, namely, the memory for general knowledge, and we can increase comprehension using non-text- based materials. Information visualization can be a powerful method to increase comprehension. In broader terms, non-text- based materials are not just representations with no words used at all, but rather representations that minimize the use of the text and instead use visualization or other means (e.g. students physically interacting with the materials) to scaffold learning.

In the graduate course that the first author (Dr. Ziho Kang) teaches, titled cognitive engineering and decision making, one of the topics focused on is teaching memory store models or theories. One representative model is the semantic network model (Glass, Holyoak, & Kiger, 1979) which explains how a comprehended concept can be stored as a network with other concepts (**Figure 1**). The concepts can be easily understood based on the visualized examples.

Lesson learned from teaching was that non-text-based materials can reduce cognitive workload, namely, the amount of mental effort put forth, using working memory, that can improve learning performance outcomes. Furthermore, students who were provided with visualized information were able to remember the contents and the meaning of the information better accompanied with increased active eye movements (Kang 2019; Kang et. al, 2019).

However, the impact of non-text-based materials in the traditional classroom environment is limited by other factors. The materials merely presented through the projector can be boring, passive students discourage engagement, and only a limited number of students can attend. Today's classroom

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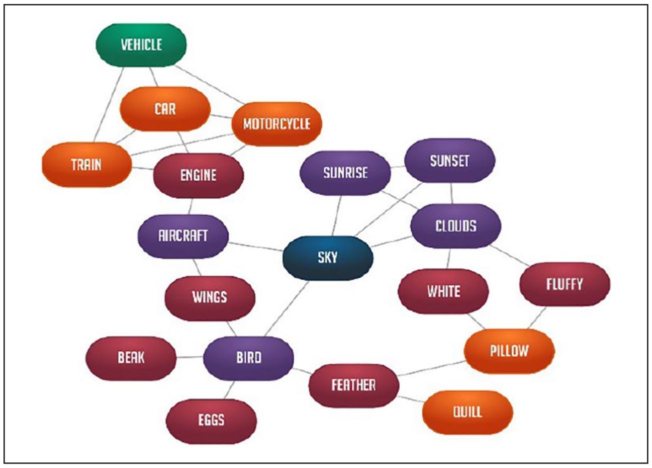


Figure 1. Example of a visualized semantic network model.

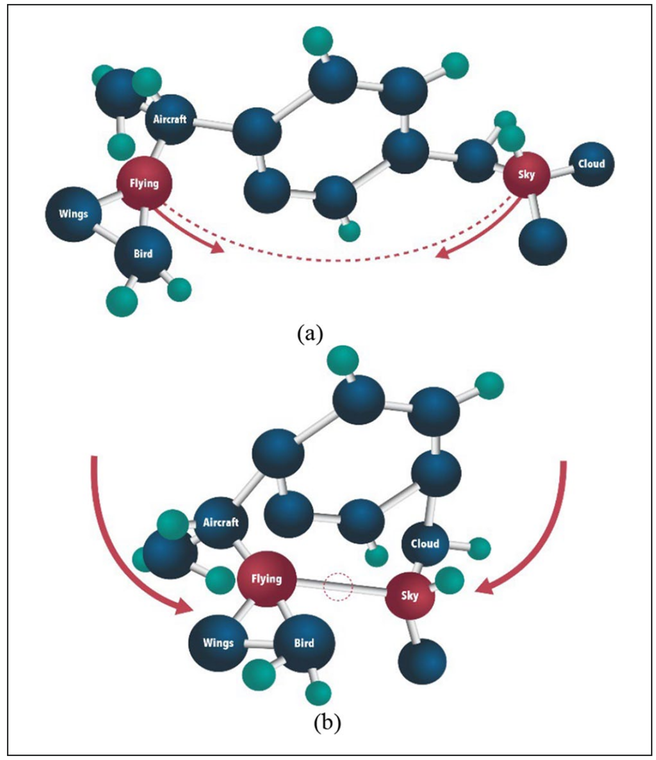


Figure 2. Example of using the 3D MVR environment to better teach the semantic network model.

requires teaching that engages students in multimodal ways due to changes in technology and in the cultural norms.

A fully immersive MVR can provide non-text-based learning opportunities which give instructors unique ways to engage students and create an innovative educational environment that connects them to material and with other learners. For example, a medical school professor can explain the human bone structure, or a flight instructor can demonstrate how to pilot an aircraft, or a military officer can provide a virtual tour of a war zone. VR can be fully immersive, eliminating distraction, and the students can 'travel' in ways their finances and other restrictions would have prevented them from doing so.

It is important for the stakeholders to understand that the MVR is not just a visual textbook. We don't want the students to think that an MVR environment will be become simply a digital textbook: students can learn the material through their peers' eyes.

An example of the power of MVR is that the instructor can effectively use the 3D space as a form of "active learning." **Figure 2** shows an example of how the 2D image in **Figure 2(b)** can be better illustrated. "Flying" and "Sky" can be difficult to connect appropriately using a 2D image. However, we can fold the nodes in the 3D space to express their close relationship. Furthermore, the students can work together by using their own interface to create their own examples and their peers can observe the process.

An issue of the MVR environment is that it is difficult to know whether each student is effectively learning during a MVR class. This is a special challenge when the students are logging into the MVR environment from remote locations and the teacher can't directly observe the students. What we need are approaches that are non-intrusive that can be measured and analyzed in real-time, or at least near real-time, and a method to address the different needs of the multiple students in the MVR learning environment.

One viable way to is to analyze the students' biometric (or physiological) measures in near real-time, especially, the students' eye movement characteristics, haptic interactions, and/or brain activities. In addition, the students' physiological measurements can be obtained in a non-intrusive manner. For eye tracking, very small infrared cameras are embedded into the VR system which the user isn't even aware of, and the haptic devices used in VR can automatically produce the interaction outputs. For assessing brain activities, the recently available functional Near Infrared Spectroscopy (fNIRS) only covers the user's forehead with a flexible band that measures cerebral hemodynamics in response to sensory, motor, or cognitive tasks, which can be worn very comfortably for a long period.

Objectives

The specific objectives for the demonstration are three-fold: (1) Provide the design concepts that were developed and implemented for a MVR semantic network app, (2) demonstrate the learning effectiveness using the MVR semantic network app, and (3) demonstrate how the near real-time biometric measurements are obtained.

Design Concepts to Develop the Mvr Semantic Network App

The purpose of the app is for the user to be able to create multiple connections among the spheres, objects, and/or images, in which the connections can be easily re-structured, saved, and shared as needed. The various types of biometric data are collected in real-time. The use of the tool is to teach the K-16 students, or the general public, the concept of cognitive semantic network. The users create their own network in MVR and can assist one another as needed. The 3D network concept (shown in **Figure 2**) has been enhanced so that actual 3D objects can be used by the users when creating a semantic network. Core design concepts are as follows.

1. **Menu**: A menu option is presented so that the user can select the following options: Connect two objects, disconnect two objects, save network, load network, and delete network. Other menu options can be added as needed.
2. **3D objects**: At an initial stage, many 3D objects of interest are placed in an orderly manner within the MVR environment. The users can walk or jump to the location within the MVR space to pick up and move the objects. Each 3D object has a set of coordinates that can be followed that enables the analysis of whether an eye fixation occurred on the object.
3. **Physics for connections/disconnections and changing the shape of a network**: The network is created by connecting two objects (i.e. nodes) with a leg (i.e. edge). If the user selects the 'connect' (or 'disconnect') menu option, then selects the two objects, then a leg is automatically created (or erased). The end point of leg is the 3D object's center coordinates (xx, yy, zz) of the object. Note that the leg penetrating into the 3D object will not show, meaning that it will look as if the leg is touching the surface of the object.

If the user moves the 3D location of an object (or objects), then all the connected legs will elongate or shorten accordingly to maintain the overall structure of the network. For example, assume that objects are connected with other objects as shown in **Figure 2** (above). If the user moves an object, then the connected legs are continuously redrawn in real-time based on the movement of the object.

4. **Saving and sharing networks**: Whenever needed, the current network being built, or the finished network can be saved and imported as needed. If some users are struggling with creating a meaningful network due to lack of knowledge and/or experience, the instructor or an experienced user can easily intervene by either working of the network together or importing/loading a saved network to provide an example.
5. **MVR environment**: Client-server network is used so that the server computer provides resources to multiple client computer over a network. As long as the server computer is running, multiple users can join as clients within the same MVR space. Note that the server computer is capable to running a client app within the server computer itself. For example, it two persons are joining, only two computers (or laptops) are needed (i.e. one computer running the server app and client 1 app, and the other computer running the client 2 app.
6. **Near real-time output of biometric (or physiological) measures from each user**: Each user's (i.e. client's) data are saved separately as a text file. Data recorded are (1) coordinates (xx, yy, zz) for the gaze location, (2) pupil diameter, (3) cerebral hemodynamic activity data of oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR), (4) coordinates (xx, yy, zz) of the virtual reality headset, and (5) coordinates (xx, yy, zz) of virtual reality controllers (both right and left).

In detail, the gaze location indicates where the user was observing while interacting in a VR environment, and the gaze location coordinates can be additionally processed to find out whether a gaze occurred on an object or a menu. The gaze locations, VR headset (or head/body) location, VR controls' locations, and pupil diameter are the variables that can be used to further investigate the task visual and peptic engagement levels of the users. The change of ΔH over time is used to investigate the relative change of cerebral hemodynamic activity (i.e brain activity). The outputs can be visualized as needed to better understand the trends and complexities.

Demonstration

The developed MVR semantic network app using the design concepts (explained above) will be demonstrated. The specific application we chose is on the users creating a semantic network based on the users' knowledge of the associations among body parts/organs and food types (i.e. which food is good for which body part/organ). Many-to-many connections are possible.

Vive Pro Eye fully immersive virtual really headsets and BioPac fNIRs devices will be used to demonstrate our developed semantic network app. The biometric measures are recorded through the Vizard and Biopac Cobi Studio API functions. The sematic network app was developed using the Python script. **Figure 3** shows the how Vivo Pro Eye and fNIRs devices are worn and how two users are interacting in the MVR space.

The demonstration steps are mapped with the steps explained in the design concepts section. Details are as follows.

1. **Menu options**: Developed menu options are provided in **Figure 4**.
2. **Layout of 3D objects**: Initial layout of the objects are shown in **Figure 5**. Note that any number of different objects can be configured and provided.
3. **Physics for connections/disconnections and changing the shape of a network**: **Figure 6** shows examples of connections. As an example, salmon is full of

Figure 3. Virtual reality head set and fNIRs device can be worn together (see (a)). Testing and evaluation the MVR semantic network app developed at the Human Factors and Ergonomics Laboratory at the University of Oklahoma (see (b)).

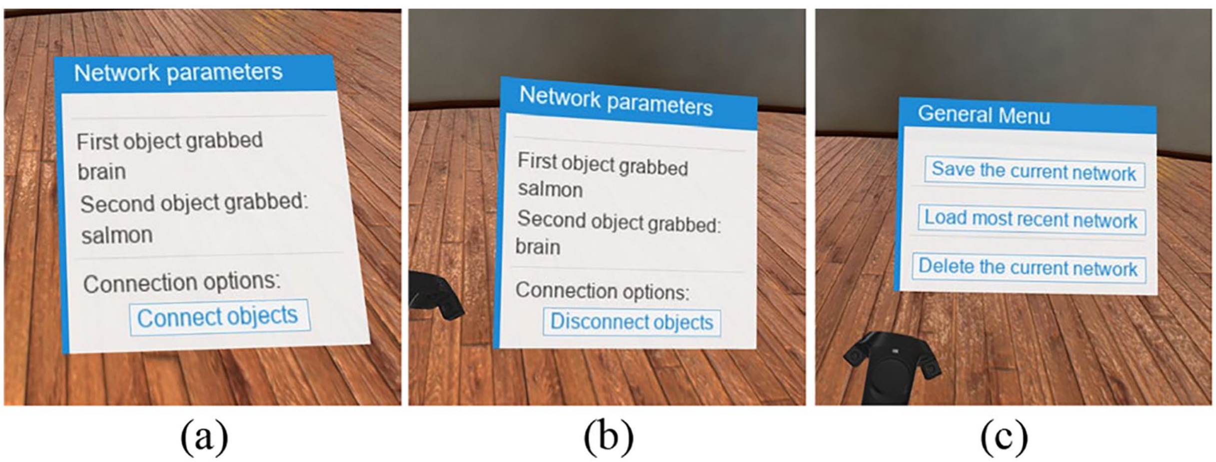


Figure 4. Menu options: (a) connect, (b) disconnect, (c) save, load, and delete network (i.e. semantic network).

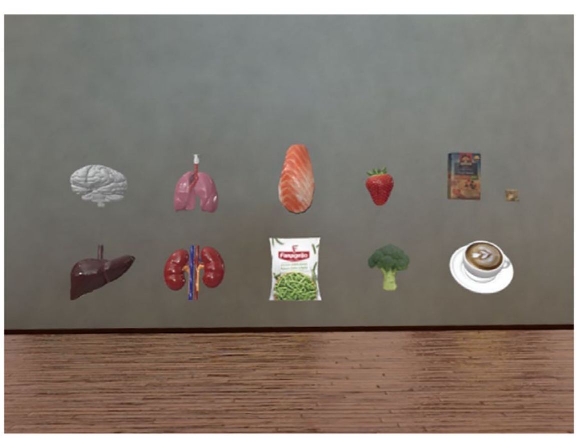


Figure 5. Layout of the objects such as brain, liver, heart, lungs, potato, salmon, coffee (in coffee cup), and broccoli.

omega 3, therefore, a connection can be created between the brain and salmon (**Figure 6(a)**). Oatmeal, coffee, and broccoli can benefit the liver, and if a user associates oatmeal and coffee more strongly than broccoli based on her/his experience (e.g. breakfast theme), the user may choose to link oatmeal and coffee more closely together than they link either of them with broccoli (**Figure 6(b)**.

Attempting to represent complex connections as a 2D network (**Figure 7 (a)**) can be difficult to create and comprehend, whereas portraying them (or adjusting their locations) in a 3D network and viewing them from various angles (**Figure 7 (b)** and **(c)**) can be much more effective. Whendealing with a network that has numerous connections, a 3D virtual reality space is an optimal choice.

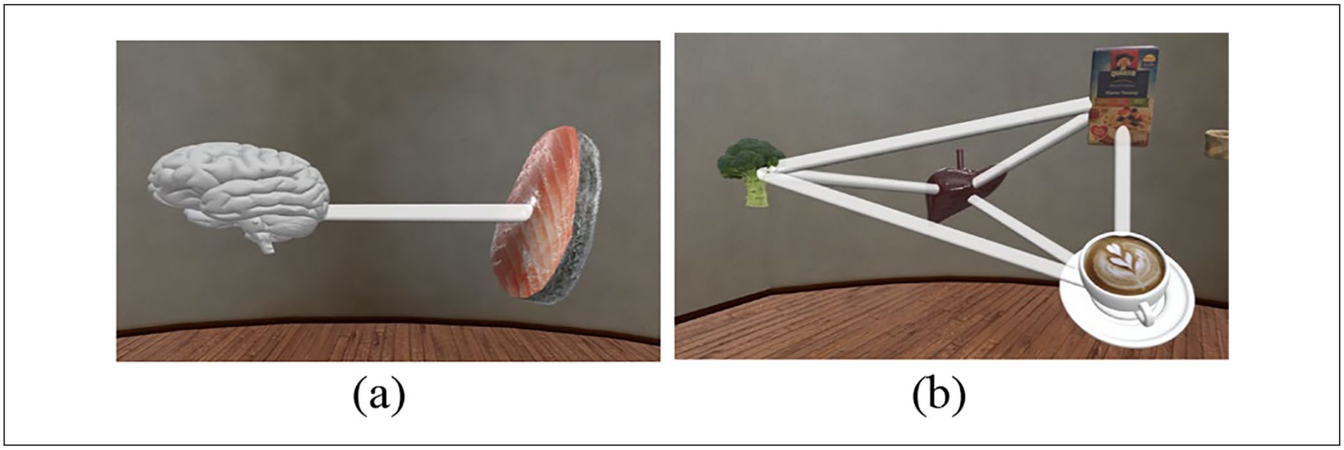


Figure 6. Examples of connections: (a) one-to-one connection (brain and salmon), and (b) many-to-many connections (liver, oatmeal, coffee, broccoli).

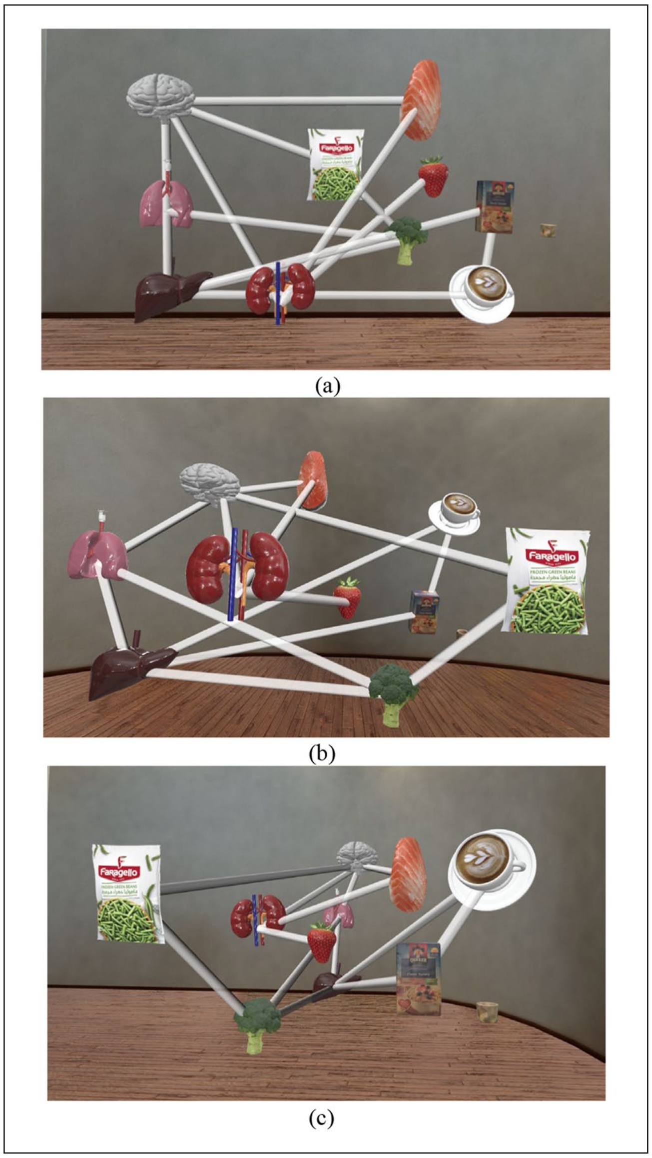


Figure 7. Examples of changing the shape of created network.

4. **Saving and sharing networks:** The created network can be saved, loaded, and/or deleted using the menu provided in (**Figure 4 (c)**). If saved, the network information is saved as a text file. If deleted, then the objects are disconnected and return to their original location. The user can re-load the saved network any point in time to share it with others (e.g. students, instructors).
5. **MVR environment**: A client can be run along with the server on the same computer (**Figure 8 (a)**). In **Figure 8 (a)**, the left image is the view from the server that shows two clients joined with the MVR environment (i.e. a women avatar and a man avatar), and the right image shows the view from the first client (i.e. man avatar). Another computer is used for the second client (i.e. women avatar) (**Figure 8 (b)**). Many clients can join at the same time.
6. **Near real-time outputs of biometric (or physiological) measures**: Sample data from one user saved in near real-time is provided in **Table 1**. Ranges of gaze points, VR headset location, and right/left hand (i.e. controller) locations within the MVR environment are normalized between -1 and 1 based on (1) VR room size and (2) initial location of the avatar (i.e. VR headset location) which is set to (0,0,0). Pupil diameter is based on millimeters, ΔH (= HbO - HbR) can be up generally up to 10 micromolar.

The data collection rate is approximately 100 hz, which is equivalent to data being collected every approximately 10 milliseconds. 3D gaze scan paths (i.e. time-order of gaze locations and saccades), 3D hand movement paths, and cerebral hemodynamic changes (ΔH) can be visualized using the near real-time outputs as needed.

An example of a 3D gaze scan path is provided in **Figure 9 (a)**. It's important to note that the "gaze scan path" we're referring to here is a visualization of raw eye movements, which differs from the term "visual scan path"

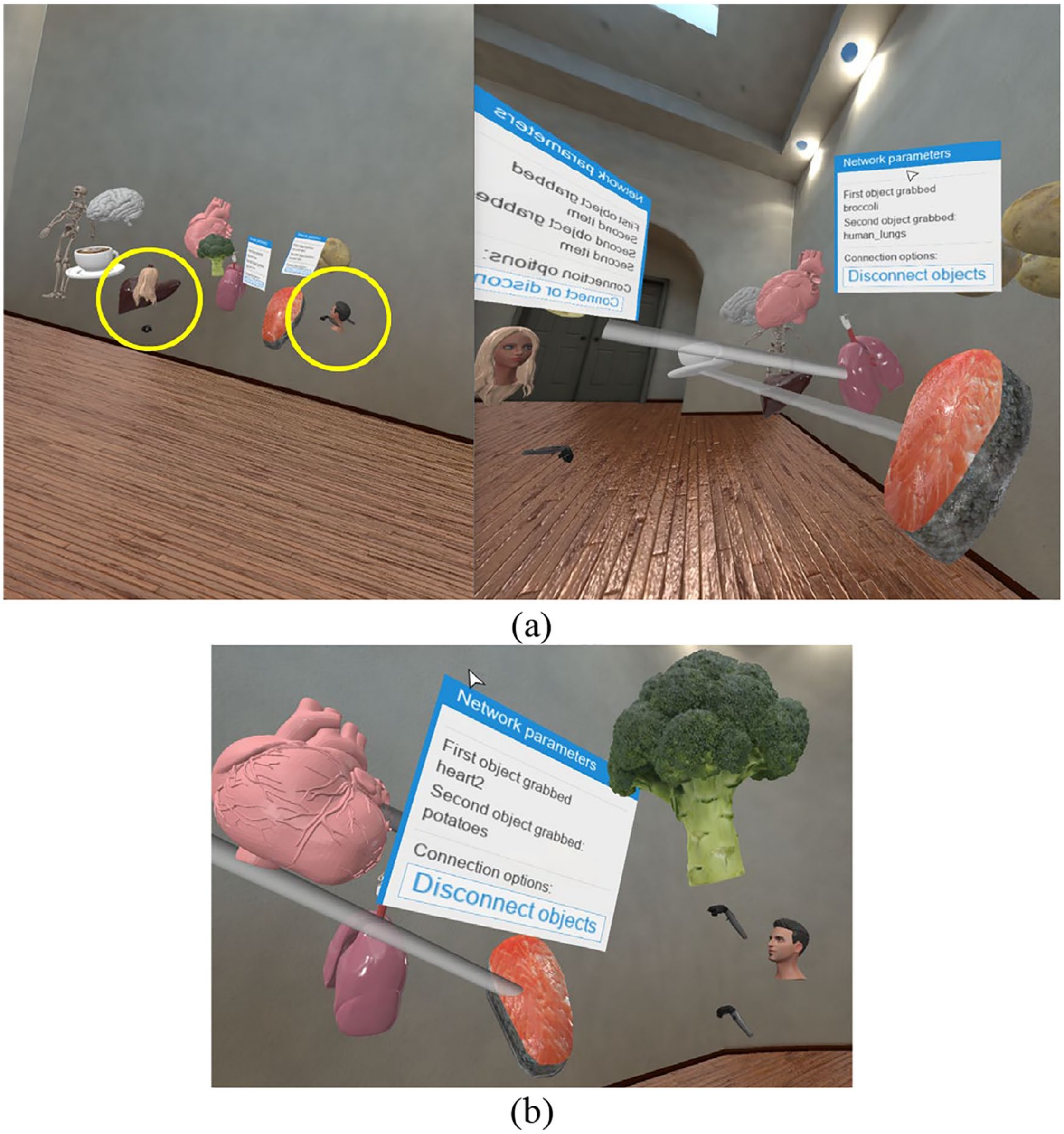


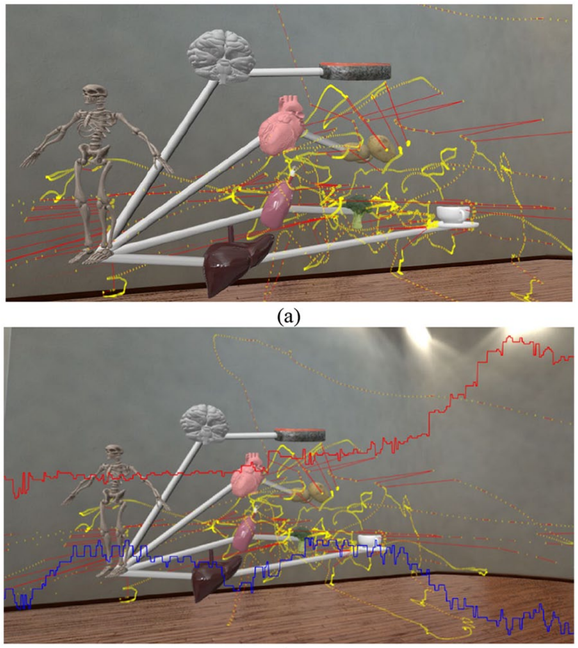
Figure 8. Example of a server with two clients (i.e. two users).

typically used in the eye-tracking research community. In this context, visual scan path generally denotes the temporal sequence of eye fixations and saccades, and eye fixations are identified by processing the raw data using specific algorithms and thresholds.

Figure 9 (b) shows a screen capture of the oxygenated (HbO) and deoxygenated (HbR) hemoglobin values, which are obtained using the Biopac Cobi Studio Software. Cerebral hemodynamic changes (ΔH = HbO - HbR) can be used as an indicator of brain activity. A higher value of ΔH corresponds to increased cerebral blood flow and oxygen consumption, which in turn indicates greater brain activity. (Izzetoglu et al., 2004).

Applications for Human Factors Researchers and Educators

We are currently investigating ways to share our app with the local communities, especially on education and training. One of the non-profit organizations we have reached out is Thick Descriptions, in which the organization has access to 600 minority and overlooked K-12 students (55% African American) in the areas of Tulsa, OKC, Norman, Boley, Guthrie, and Shawnee. In addition, we are hoping that our developed MVR environment can trigger interest from wide audiences, especially K-12 teachers and students. In addition, through this demonstration, we plan to foster interest



(a)

(b)

Figure 9. Examples of collected biometric data: (a) Raw data of eye movements, and (b) HbO (red line) and Hb (blue line). Other data provided in **Table 1** can be plotted as needed.

Table 1. Data format and sample data.

Milli- seconds	Gaze *x*	Gaze *y*	Gaze z	Pupil diameter	HbO	HbR
1000	-0.79	0.72	0.62	0.41	2.26	1.64
1010	-0.82	0.83	0.60	0.42	2.25	1.63
Milli-seconds	Head *x*	Head *y*		Head z		
1000	-0.56	0.80		0.84		
1010	-0.52	0.79		0.83		
Milli-seconds	Right hand *x*	Right hand *y*	Right hand z	Left hand *x*	Left hand *y*	Left hand *z*
1000	-0.32	0.88	0.92	-0.38	0.86	0.18
1010	-0.31	0.89	0.91	-0.39	0.87	0.19

from human factors researchers and teachers to receive feedback and collaborate on how to enhance and distribute the app for broader impacts activities.

Ongoing and Future Research

The MVR semantic network app is one of the teaching/learning apps that are being developed at the Human Factors and Simulation Laboratory (Director: Dr. Ziho Kang) at the University of Oklahoma. Other ongoing research activities include, but are not limited to, improving the near real-time analysis capabilities (Kang, 2017; Palma-Fraga et al., 2021), developing algorithms to better visualize the real-time data, investigating the correlations among the various biometric measures (Naeeri et al., 2021), and address the diversified needs among individual based on Universal Design and Learning concept (Rose, 2000).

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