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Human Vertebral Columns Learning Using Hand Gesture Interaction

Ang Wan Xin and Nur Zuraifah Syazrah Othman
Faculty of Computing
University of Technology Malaysia
81310 Johor Bahru, Malaysia
angxin@graduate.utm.my, zuraifah@utm.my

***Abstract*— Science, an essential component of the STEM acronym (Science, Technology, Engineering, and Mathematics), allows people to understand how and why things work. However, learning anatomy in science education is challenging due to difficulties in visualizing internal structures. One of the structure, human vertebral column, is particularly hard to grasp due to its deep location within the body. Additionally, many young people suffer from back pain caused by poor sitting posture, making understanding the human vertebrae vital. Therefore, this project aims to create a human vertebral column learning application using hand gesture interactions. This project was carried out in three phases. The first phase involved requirement analysis, focusing on studying and analyzing information about user interaction requirement and techniques, hand gesture interaction and Leap Motion technology. The second phase was the design phase, where hand gesture interactions, system design, database design, and interface design were developed. The final phase was implementation, where hand gesture interactions were integrated into the application. The evaluation was based on user acceptance testing and usability. The results showed that users could perform most actions without prior knowledge of the system. The application achieved a mean score of 87.30 on the System Usability Scale (SUS), which is above the average score of 68. Based on the results, this project has successfully produced a learning application for the human vertebral column using hand gesture interactions, significantly improving user experience and understanding of human vertebrae.**

Keywords- human vertebral columns; leap motion; hand gesture; learning

I. INTRODUCTION

Science has two components, the known knowledge and the process of gaining new insight through a series of experimentation steps, including observation, experiment, testing, and hypothesis formulation [1]. In education, science covers a wide variety of subjects such as Biology, Physics, Chemistry, Astronomy, and other subjects. Anatomy is one of the most complicated subjects in the field of biology for students to study the structure and abstract nature of the human body [2].

Human anatomy consists of eleven organ systems that control all vital body functions. Skeletal systems are one of the organ systems that support and protect the body's internal organs. The spinal cord and the fluid around the spinal cord are encased by vertebral columns and consists of a pair of spinal nerves that allow communication with whole body, including brain and body [3]. Hence, it is important to take care of the vertebral columns.

Learning human vertebral columns can be a difficult endeavour since it requires the study of complicated anatomical structures that might be difficult to comprehend through visualization alone. In addition, due to the vertebrae are located deep within the body, it is difficult to visualize and comprehend the structure and function. Therefore, there is a need for innovative approaches to learning the anatomy of human vertebrae. One of the approaches is by using gesture interactions. Leap Motion Controller is an optical hand tracking device that captures hand gestures with unrivalled accuracy [4]. Hand gesture interaction is a natural means of interacting since hands are being used for interacting with tangible objects all the time.

This paper presents the development of a gesture interaction learning system on human vertebral columns using Leap Motion Controller which allows users to interact and manipulate the vertebral columns.

II. LITERATURE REVIEW

This section discusses literature review for the hand gesture, hand gesture interaction and gesture input device.

A. Hand Gesture

Hand gesture can be defined as the movement or position of the hand and fingers to convey an idea to others [5]. Hand gestures can be purposeful or unconscious, and used to communicate in several circumstances, including conversation, public speaking, artistic performances, and technological interfaces.

Hand gestures can be classified into two main categories which are static hand gestures and dynamic hand gestures [6]. Static hand gestures are those in which the hand is held in a set of positions or postures to express something of significance. On the other hand, dynamic hand motion incorporates hand and arm movement to communicate meaning.

A. Hand Gesture Interaction

There are several gestures implemented in the system along with the interaction assigned to it. Tap gesture is used to perform select interaction in the application. For example, the users use tap gesture by extending the index finger to select the button to perform actions [7]. Spawn interaction is performed by the open palm gesture or tap gesture in the application. This interaction is used to instantiate the hovercast virtual reality (VR) hand menu that attach to the hand or the three-dimensional (3D) human vertebral columns.

Grab gesture is used to translate the 3D object when the object is being grabbing. Point gesture is used to select the object and then moved towards left or right for rotating the object via certain axis. Rotate on wrist gesture is also used to rotate the object when the object is grabbed. Pinch gesture with both hands is used to perform the scale interaction whereas cut gesture is used to perform the separate interaction.

B. Gesture Input Device

A gesture input device is a hardware or software system that collects and interprets human gestures as an input method. There are several gesture input devices that are able to track and interprets human gestures such as Leap Motion, Microsoft Kinect, Data Glove and ManoMotion. Table 1 shows the comparison of the gesture input devices.

TABLE I. COMPARISON OF GESTURE INPUT DEVICES

Device	Components	Performances	Accuracy
Leap Motion	Two infrared cameras and three infrared LEDs	Detect palm and finger gestures movement	Detect range of 25 mm up to 600 mm with a field of vision of 150 degrees
Microsoft Kinect	A mix of cameras, microphones, and depth sensors	Detect full-body human 3D motions, facial recognition, and voice recognition	Detect range of 1.2 – 3.5 m
Data Glove	Various sensors on each joint finger and hands	Detect the hand's angular velocities, accelerations, and joint angles	High accuracy when more sensors are used
ManoMotion	Standard RGB camera to detect gestures	Detect hand gestures for hand tracking and gesture analysis	Detect range of 0.3 – 1.2 m from camera

This project focuses on hand gesture interaction, making Leap Motion Controller (LMC), Data Glove, and ManoMotion more suitable than Microsoft Kinect, which emphasizes full-body movement. LMC, Data Glove, and ManoMotion provide better accuracy for hand gestures due to the closer range capabilities. However, Data Glove is costly and less accessible, and ManoMotion has limitations in supporting diverse gestures such as cut, pinch, and rotate on wrist gestures. Therefore, LMC emerges as the optimal choice for hand gesture recognition in this project, offering effective detection of gesture movements at a reasonable cost and availability.

III. SYSTEM DEVELOPMENT METHODOLOGY

The Waterfall model was chosen as the system development methodology for this project. It also refers to a linear-sequential life cycle model which indicates that the next phase can only begin after the previous phase is completed [8]. This model matches the system development of the project. Fig. 1 illustrates the project methodology phases.

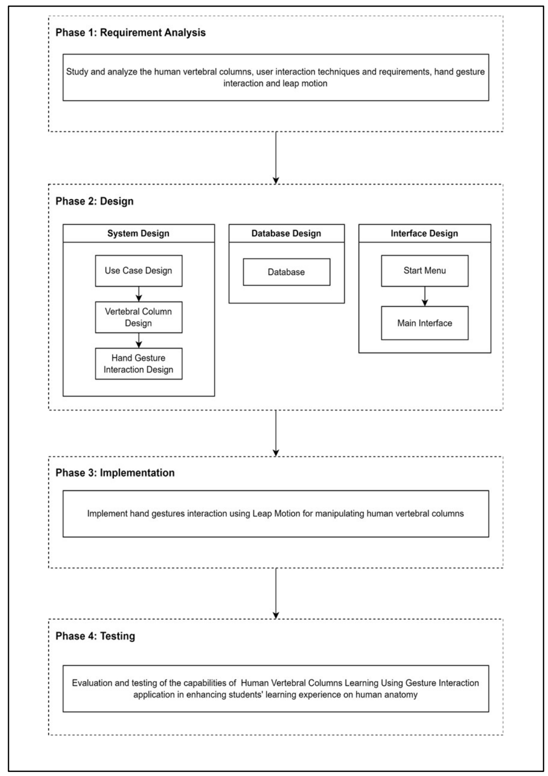

Figure 1. System framework flow

A. Requirement Analysis Phase

The requirement analysis phase was researching and analyzing the information related to the proposed project. The essential concept of the human vertebral columns in the secondary school level is studied so that it would be easier to apply in this learning system. Moreover, research on gesture input devices is also conducted to determine the optimal input device for this project. The section on hand gesture interaction is also included in the literature review to assist in identifying relevant gesture interactions for the project. Existing applications are also investigated and analyzed, and a comparison of the applications is conducted to get the requirements and understanding that are needed to build and construct the system architecture. A study on Leap Motion and the game engine is also carried out in this project to get a better understanding of the concept to be used.

B. *Design Phase*

The second phase of the methodology in this project is the design phase which includes technical parts to meet the project requirements. In this phase, system design, interface design, and database design are included. In the system design, the use case diagram is created following with the vertebral columns design and hand gesture interaction design. The vertebral columns design is taken from the available 3D model that exists on the Sketchfab website. Hand gesture interaction design included the selection of hand gesture inputs that are required for the interaction. In database design, the database consists of tables that are used to store the description of the vertebrae group and the feedback provided by the user. The feedback and email from the user will be saved into the database for future improvements.

In interface design, the system interface is planned and built to make it easier for the user to engage with the system. A user interface (UI) can act as a guideline for users to interact with the system. The interface design is split into several parts which are start menu, learning interface and quiz interface. The user can tap on "Start" to navigate into the learning interface. The user can then manipulate the vertebral columns based on the hand gesture interaction implemented. After that, the user can choose to navigate to quiz interface to answer the questions to obtain the learning outcomes.

C. *Implementation Phase*

The third phase of this project is the implementation phase. In this phase, the designs from the previous phase are used to develop the system by utilizing the necessary technologies. The software and devices used to develop the project are Unity3D and Leap Motion Controller (LMC). The hand gestures interaction is implemented with the aid of LMC in this system to manipulate the vertebrae. The development starts with building the scenes based on the interface design. There will be several interactions for the user to manipulate the human vertebral columns. The script of the algorithms is written using Visual Studio Code.

D. *Testing Phase*

The final phase of the methodology in the project is the testing phase. User testing is carried out to get feedback and comments from the user. It can help to improve the satisfaction of the system to ensure that the system fulfils all the project's requirements. Besides, black box testing, which is also known as behavioral testing, is also be implemented to evaluate the application as it concentrates on assessing the system's functionalities without having previous knowledge of the internal operating structure [9]. The user can test the features or specific functions of the system and see whether the system can produce desired output based on the selected inputs. The evaluation followed Obrero-Gaitán's [10] method as a guide for user testing and utilized the System Usability Scale (SUS) developed by Brooke [11] to measure perceived usability. SUS is a widely used tool which consists of a 10-item questionnaire with responses ranging from Strongly Disagree to Strongly Agree. The testing included a total of twelve participants which followed Belanová and Yoshida's testing [18] as a reference.

IV. Design and Implementation

This section explains the design and implementation of the system. Fig. 2 shows the use case diagram of the system which includes all features in the application.

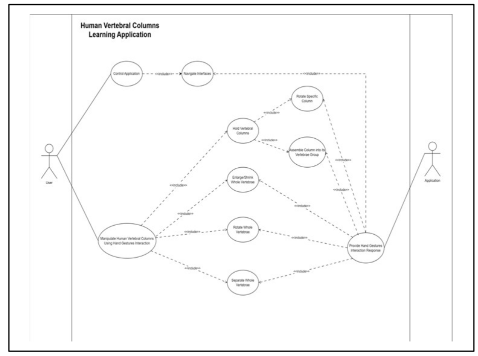

Figure 2. Use case diagram

A. *Implementation of Hand Gesture*

There are several types of hand gestures used in the application for interaction.

1) *Pinch Gesture*

The pinch gesture is implemented for scaling vertebrae in the system involves using both hands, with each hand's data stored separately. The pinch distance between the thumb and index finger is tracked and the positions are retrieved. The distance between the hands is calculated to determine scaling actions. Two conditions are to check if the pinch gesture is correct: the pinch is detected and a pinch distance under 20. Scaling decisions are based on hand distance changes: hands moving apart indicate enlarging, while moving closer indicates shrinking. Scaling is smoothly managed with the Lerp function, ensuring vertebrae do not scale below a minimum or above a maximum size. Fig.3 shows the pinch gesture for scaling.

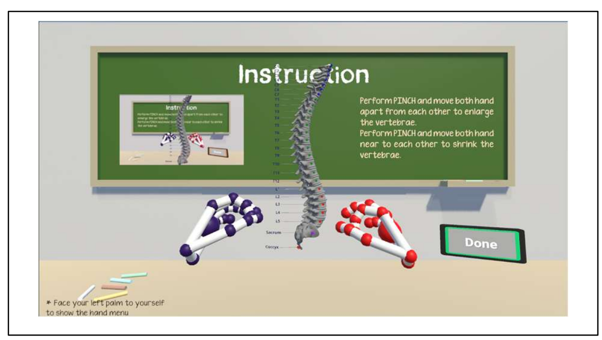

Figure 3. Pinch gesture for scaling

2) *Point Gesture*

The point gesture is used to rotate the vertebrae along the y-axis: pointing left rotates the vertebrae clockwise, and pointing right rotates them counterclockwise. Ultraleap SDK's Hand Pose Detector script is used to detect the point gesture and then sets the boolean accordingly. The index finger's x-axis position difference between frames determines the movement direction. If the position difference is positive, the user is moving right; if negative, moving left. Upon detecting the point gesture, the vertebrae rotate using Transform.Rotate, with rotation speed adjusted based on movement direction and elapsed time, ensuring smooth local coordinate system rotation. Fig. 4 shows the point gesture for rotation.

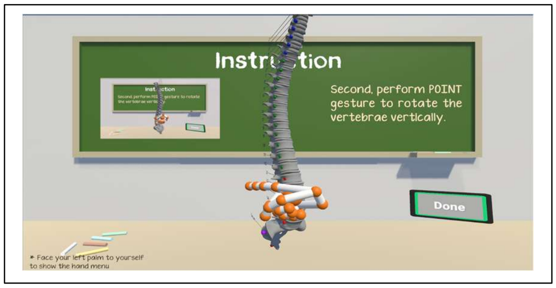

Figure 4. Point gesture for rotation

2) *Grab Gesture*

Grab gesture is implemented in the system to let the user grab, assemble and disassemble the vertebrae. Grab gesture is detected by checking whether the grab strength of the user is greater than 0.8 value with the boolean is not set to true. Grab gesture is only set to false if the grab strength is less than 0.7 with grab gesture is true in the beginning to avoid jittering happen. Fig. 5 shows the grab gesture.

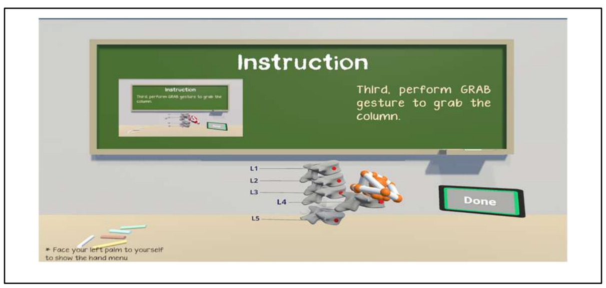

Figure 5. Grab gesture

3) *Tap Gesture*

Tap gesture is implemented using built-in gesture provided by Leap Motion in this system. By default, the Leap Motion can detect the tap gesture of the user when the user performs tapping towards the button. An Interaction Button script is added to the button game object to let the 3-dimensional (3D) button perform as a button. A Rigidbody component is added to the game object with the constraint of freeze rotation set to true for all axes. Box collider component is also added to let the user's hand be able to collide and perform any actions. Fig. 6 shows the tap gesture.

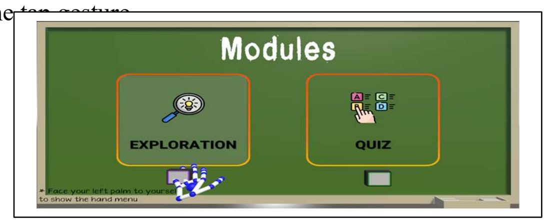

Figure 6. Tap gesture for button

4) *Open Palm Gesture*

Open palm gesture is used to show the hovercast virtual reality (VR) menu in the scene. The script used in this gesture is the built-in script provided by Ultraleap which is called Simple Facing Camera Callbacks script. It is a script that is used to detect whether an object's transform is currently facing the camera or not. For this gesture, a palm downward transform is placed in the center of the palm and dragged into the script's inspector. When it is facing the camera, the hand menu game object is set to true and the hand menu game object is set to false when it does not face the camera. Fig. 7 shows the hand menu.

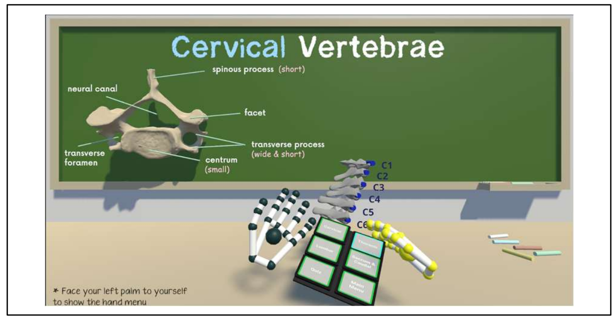

Figure 7. Open palm gesture to show hovercast vr menu

5) *Cut Gesture*

The cut gesture, performed only with the right hand, separates the vertebrae into groups during exploration. Using the Ultraleap SDK's Simple Facing Camera Callbacks script, the system detects a downward-facing palm and sets a boolean to true when the palm faces the camera. The palm's y-axis position difference between frames determines if the hand is moving down. If the user performs the cut gesture and moves the hand downward, the CutVertebrae function is triggered, translating the vertebrae along the z-axis in the local coordinate system until a threshold is reached, effectively separating the vertebrae. Fig.8 shows the cut gesture.

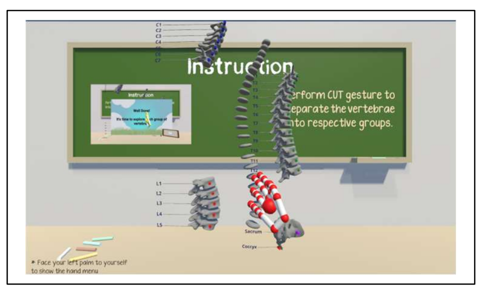

Figure 8. Cut gesture

B. *Implementation of Quiz System*

The quiz comprises five questions: four randomized from multiple-choice questions (MCQs) and grabbable game object questions, and one fixed assemble vertebrae question. MCQs and grabbable questions are stored in separate lists. A class stores each question's information and answer. The system randomly selects questions from the lists for the first four questions, and the fifth question is always the assemble vertebrae question. For the assemble question, the system uses a counter to track the assembly process. When all vertebrae are correctly assembled, verified by matching anchors, a correct panel is displayed; otherwise, users can retry the assembly.

C. Implementation of Database

The system uses a Firebase Realtime Database to manage vertebrae data and user feedback. The database stores feedback and retrieves data for vertebrae like the Atlas. For other vertebrae, the retrieval algorithm is the same, with adjustments to the database reference child names.

V. Evaluation

Twelve Form 4 biology students participated in an experiment conducted during biology class at SMK Seri Pulai Perdana. The setup included a laptop with the application, a Leap Motion Controller, and a user. The Leap Motion Controller is attached to the laptop on a flat surface. Students sat in front of the laptop, placing the hands above the controller, which rendered the hands as virtual hands on the screen as shown in Fig.9. If hands moved outside the controller's scanning region, the virtual hands disappeared.

Figure 9. Palm downward transform for cut gesture

B. Black Box Testing

This section describes the user acceptance testing that is conducted via black-box testing, where 12 respondents used the application without prior instructions. Figure 10 presents part of the user acceptance testing for the actions to be completed. A tick indicated success action whereas a cross for failure.

No	Action	Expected Result	Actual Results by Target User											
			1	2	3	4	5	6	7	8	9	10	11	12
1	Tap on buttons in Main Menu	Start – Navigate to Choice Menu UI	√	√	√	√	√	√	√	√	√	√	√	√
		Learning – Navigate to Gesture Learning UI	√	√	√	√	√	√	√	√	√	√	√	√
		Quit – Close the application	√	x	x	√	x	√	x	√	x	x	√	x
2	Tap on buttons in Choice Menu	Exploration – Navigate to Exploration UI	√	√	√	√	√	√	√	√	√	√	√	√
		Quiz – Navigate to Quiz UI	√	√	√	√	√	√	√	√	√	√	√	√
3	Perform pinch gesture in exploration scenes	Pinch Towards Each Other – The vertebrae are zoom out	√	√	√	√	√	√	√	√	√	√	√	√
		Pinch Apart From Each Other – The vertebrae are zoom in	√	√	√	√	√	√	√	√	√	√	√	√
4	Perform point gesture in exploration scenes	Point Left – The vertebrae are rotated clockwise	√	√	√	√	√	√	√	√	√	√	√	√
		Point Right – The vertebrae are rotated anticlockwise	√	√	√	√	√	√	√	√	√	√	√	√

Figure 10. Part of user acceptance testing results

Based on the result, all actions were completed, though some were skipped: 7 respondents did not quit the application, 9 did not use all hand menu functions in the exploration UI, and 8 did not reset the vertebrae position in quiz question 5. This is due to the familiarity with gesture interactions and the proximity of buttons causing missed taps. Additionally, only 4 respondents restarted the quiz, and various navigation choices were made based on perceived necessity and familiarity.

A. User Testing

For the user testing, a set of questionnaires is prepared for the user to fill in before and after the testing. The questionnaires consist of pre-test questions and post-test questions.

The testing involved 12 Form 4 students that are equally divided by gender, all aged 16. All respondents had studied the vertebral column topic in biology and only 2 of them had prior experience with the anatomy learning application. Additionally, none of them had used a Leap Motion Controller or hand gesture interactions for any application, indicating that users were new to application that implement hand gesture for interaction.

The user testing results show that the Leap Motion Controller accurately recognizes gestures, with 75% of respondents agreeing and 16.7% strongly agreeing. Most respondents found gesture interactions easy to use: 91.6% for navigating scenes with the left palm hand menu, 100% for the tap gesture, 100% for the pinch gesture, 91.7% for the point gesture, 100% for the grab gesture, and 100% for the rotate on wrist gesture. However, 33.3% were neutral about the cut gesture's ease of use. Overall, the gestures were well-recognized and interactions were user-friendly, as most respondents rated them positively.

The feedback from respondents indicates strong approval of the application's effectiveness in aiding understanding and learning about the human vertebral column. Half of the respondents agreed, and the other half strongly agreed that the application helped them understand the vertebral columns. Additionally, the majority found gesture interactions effective or very effective for learning anatomy. Most respondents also agreed or strongly agreed that the application enhances the overall learning experience and are likely to recommend it to others interested in learning about the human vertebral column. Overall, the application received positive feedback for its educational effectiveness and user recommendation.

System Usability Scale (SUS) is known as a tool for measuring the usability of the application which was created by Brooke [12]. A score of 68 or more on the SUS is considered above average, while scores below 68 indicate below-average for the system usability [13]. The System Usability Scale (SUS) results reflect highly positive perceptions among respondents regarding the application's usability and integration. Fig.11 shows the result of SUS. The mean score of SUS for all respondents was 87.30, which is above the average score of 68. It is clear from the SUS results that most of the users had positive user experiences while using human vertebral columns learning using gesture interaction for learning the backbone. Therefore, it can be said that the Human Vertebral Columns Learning Using Gesture Interaction application is usable. Overall, the SUS results indicate strong user satisfaction and confidence in the application's usability and functionality.

Questions / Users	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Score
1	4	4	2	3	4	4	3	4	4	3	90
2	4	3	3	4	4	4	3	4	3	4	90
3	4	4	4	2	3	4	3	3	4	3	85
4	3	4	4	4	4	4	3	4	4	4	95
5	4	3	4	4	4	3	4	3	3	3	87.5
6	3	3	4	3	3	3	3	4	4	3	82.5
7	4	4	3	4	4	4	4	4	4	4	97.5
8	4	3	3	3	3	3	3	3	3	2	75
9	3	4	3	3	3	4	4	4	4	4	90
10	4	4	3	3	4	4	3	3	4	4	90
11	4	4	3	3	4	4	3	4	4	3	90
12	3	3	2	2	4	4	2	3	4	3	75
Mean SUS Score											87.30

Figure 11. Result of sus

VI. Conclusion

In conclusion, this project successfully achieved its objectives of analyzing user interaction requirements and techniques, designing and developing a human vertebral column learning application for secondary school students using Leap Motion, and evaluating its effectiveness. However, challenges such as Leap Motion Controller overheating, tracking limitations, and dependency on internet connectivity for database access were encountered. Future improvements of this project could focus on adding sound effects, realistic physics simulations, and expanding gesture interactions to further enrich user engagement and learning outcomes.

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