Virtual Reality Percussion Simulator for Medical Student Training

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***Abstract*— As the 'inventor' of percussion as a diagnostic tool, Leopold Auenbrugger can be considered one of the founders of modern medicine** [1], [2]**. As a technique it enabled clinicians to identify pathologic changes within a patient in real-time – changes which, until then, had only been identifiable posthumously by way of autopsy. In 1761, having spent seven years working in clinical settings, Auenbrugger published a work entitled "New Invention by Means of Percussing the Human Thorax for Detecting Signs of Obscure Disease of the Interior of the Chest", in which he described four percussive tones, relating each to specific illnesses. The technique is still relevant today, but the sounds, of which 5 types have now been classified, are nonetheless tricky to identify as they are not so obviously distinct from one another. Training medical staff is therefore key, and in the light of the current pandemic, during which training opportunities with real live patients have been somewhat limited, interest in training with virtual patients has increased. The haptic virtual reality** [3] **simulator provides a means to this end, enabling excellent training opportunities for medical staff in a safe and economically viable environment.**

Keywords—Percussion, Virtual Reality, VR, Simulator, Medical, Physical Diagnosis, Training, mannequin substitute.

I. INTRODUCTION

Percussion is generally used on the thoracic and abdominopelvic body cavities [4],[5]. Originally, the procedure was performed on the skin surface using a small hammer called a plexor, but nowadays is achieved by tapping the fingers of the examiner's hands against the patient's body [6]. The percussive taps can be gentle or firm, with the rebound sounds produced varying in intensity, duration, and resonance [7]. Percussion helps us to detect the presence of fluid where there is usually air, to assess the density of solid organs such as the liver, and to determine the shape and size of internal organs by using sound variations to define their outline [8], [9]. Another outcome of enormous diagnostic value is the vibratory response of the body wall when tapped, with signs of discomfort or tenderness offering important diagnostic clues. Heart percussion can also yield vital information. The heart houses a fibrous sac, the pericardium [10], which can accumulate incompressible fluid, constraining and obstructing the natural beating motion of the muscle – a potential precursor to heart failure. Similarly, the usually resonant sound coming from the chest cavity outside the lungs can become dull as fluid collects in these closed spaces [11], compromising normal lung inflation and deflation. Although an invaluable diagnostic skill, percussion has become underutilised, with medical professionals seemingly more inclined to turn to technologically advanced diagnostic imaging to establish these kinds of pathological events and changes within a patient's body cavities.

II. METHODS AND MATERIALS

When using the proposed simulator, the user 'sees' their entire body movements in virtual reality from a first-person perspective. We have mounted a Leap Motion [12] on a virtual reality headset to track and estimate the entire body's position in real-time with excellent results. Our program does not use controllers and operates using body gestures as input, employing the attached Leap Motion sensor. The resulting perception in the user's mind reinforces the feeling of immersion, and there is proof that increasing immersion also increases the capacity of users to learn within the context of virtual reality [13]. To further increase user immersion, our simulator system is programmed so that the user's body cannot penetrate the patient's body or other objects in the simulated world, thereby creating an additional illusion of physical interaction with the virtual environment [5][6].

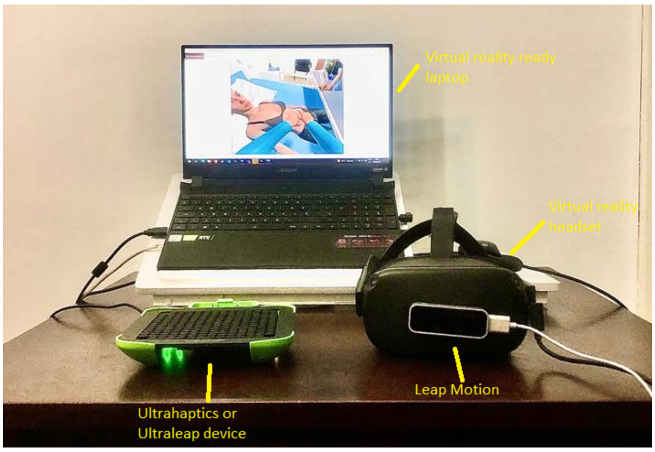

Figure 1. *We require a virtual reality headset, a Leap Motion, and a "VR ready Laptop". It is possible to connect several ultrasound-based haptic devices and a monitor.*

III. CREATING THE SIMULATOR

Creating realistic, impenetrable patient avatars, whose skin and tissue deforms on touch, further increases the user's sense of being in an alternative reality. To create the inner organs, Fusion 360 and Human Anatomy Atlas 2019 software provided good results. The simulator includes the following organs for percussive purposes:

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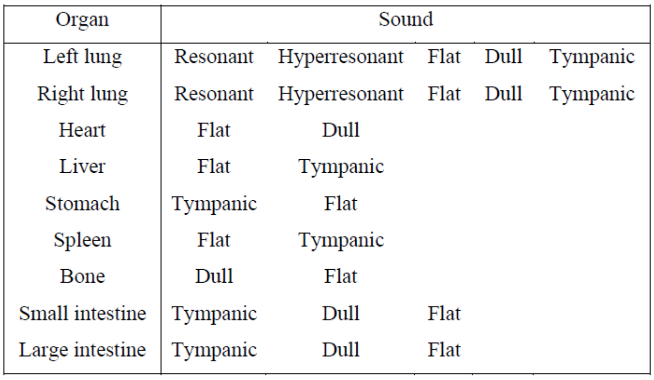
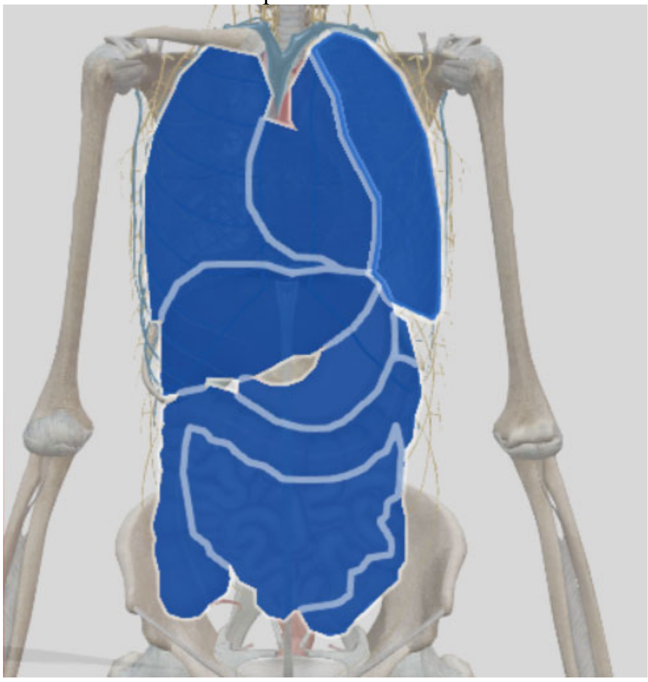


Organ	Sound				
Left lung	Resonant	Hyperresonant	Flat	Dull	Tympanic
Right lung	Resonant	Hyperresonant	Flat	Dull	Tympanic
Heart	Flat	Dull			
Liver	Flat	Tympanic			
Stomach	Tympanic	Flat			
Spleen	Flat	Tympanic			
Bone	Dull	Flat			
Small intestine	Tympanic	Dull	Flat		
Large intestine	Tympanic	Dull	Flat		

Table 1. *A table showing the sounds that each organ emits upon percussing. The simulator selects all the sounds at the launch of the simulator. After checking 200 random samples with five sounds per organ, the sounds that cannot happen at certain places were eliminated. The simulator then randomly chose a sound from the table above for each organ. The study concluded that the behaviour of each organ is independent of other organs' diseases.*

After dissecting the virtual corpse in Human Anatomy Atlas 2019, a screenshot of the dissection (see *figure 2*) was exported into Fusion 360 to add depth to the organs (*see figure 3)*. This process helped create realistically good enough 3D organs for the simulator. In addition, the organs exported to the Unity graphics engine have codes attached to recreate the percussion sounds upon collision with the user's hands. These codes include collision speed acquisition to help determine how hard the percussion should sound.



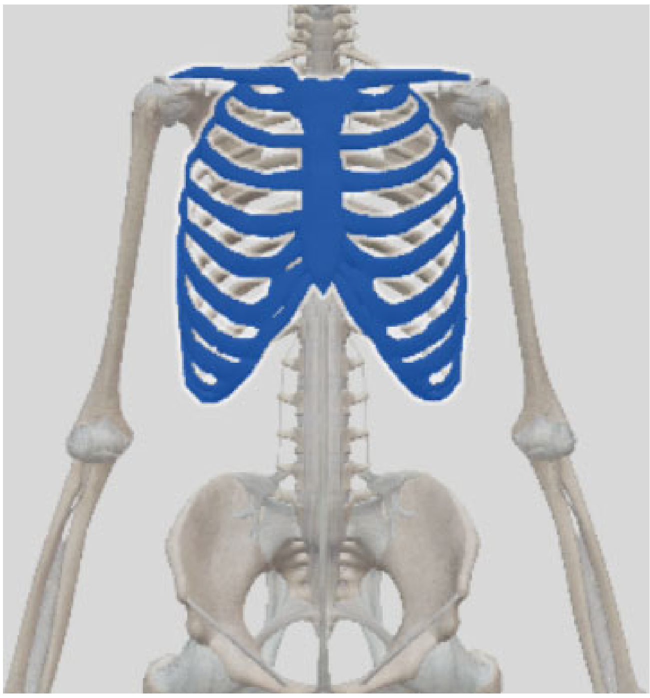


Figure 2. *Human Anatomy Atlas's software helped dissect a virtual body and get realistically good enough images to create the simulator's organs. The organs' shape is then given a volume and exported into the Unity graphics engine.*

The organs were reshaped in Unity in accordance with the patient's avatar's 'physical' characteristics. To create the characters, Reallusion's Character Creator suite was used, those characters animated with Reallusion's IClone 7 both breathe and exhibit facial expressions as well as skin deformation upon touch. The different organs inside the patient's avatar are modelled by our approach, and percussion sounds play when hands collide with them. There are scripts inside the organs that generate a random normal organic sound. The body and the organs both display 'physical' properties, such as friction, weight and deformation; because of the avatar's ability to deform when touched, the internal body parts can be percussed with the help of a mesh deformation code called Vertexmotion. The whole area has colliders added to achieve the sensation of touch. A collider is a code that helps the simulator decide whether a 3D surface should be impenetrable and/or deformable. This configuration is novel in medical simulators enabling us to experience pseudo haptic feedback throughout the entire body, heightening the sense of realism. Ultrasound-based haptics can further increase the sense of realism, combining haptics and pseudo-haptics.

It took some practice to position the organs correctly within the patient – a process in which we were assisted by medics.

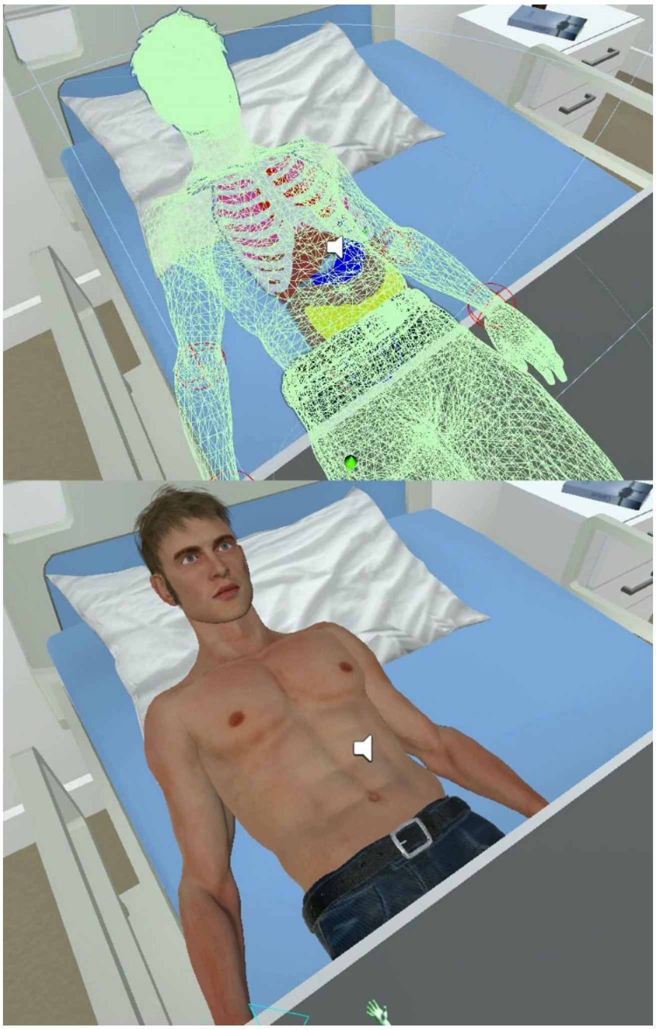


Figure 3. *(Top) The organs inside the virtual patient's body, the green mesh is the collider. The collider deforms well enough to touch the inner organs and spark the collision sound. (Bottom) The organs covered with textures that make them invisible.*

IV. THE ALGORITHM

The decision to rule out disease combinations that cannot co-exist in real life helps avoid confusion while learning on the simulator. This involved a medical evaluation of hundreds of random disease combinations.

There are male and female characters, with subtle differences in the proportions of the organs.

The whole program design mimics a workstation, like in factories, where a workstation is a workspace designed to reduce the amount of movements of the employee, to assure that they can work at optimum performance which means that medical staff using our simulator only need to walk a few steps at most, reducing the amount of space required to use the simulator. Because the user is not required to move, two Ultrahaptics or UltraLeap devices can provide haptic feedback. Ultrasound-based haptics seems to increase immersion and engagement (by providing different frequencies that relate to different sensations of touch on each organ), but devices are costly and not actually essential for the purposes of this simulator. Importantly, our system requires no physical input devices, no special garments and no exoskeletons. The hardware is comfortable and setting it up is easier than with alternatives.

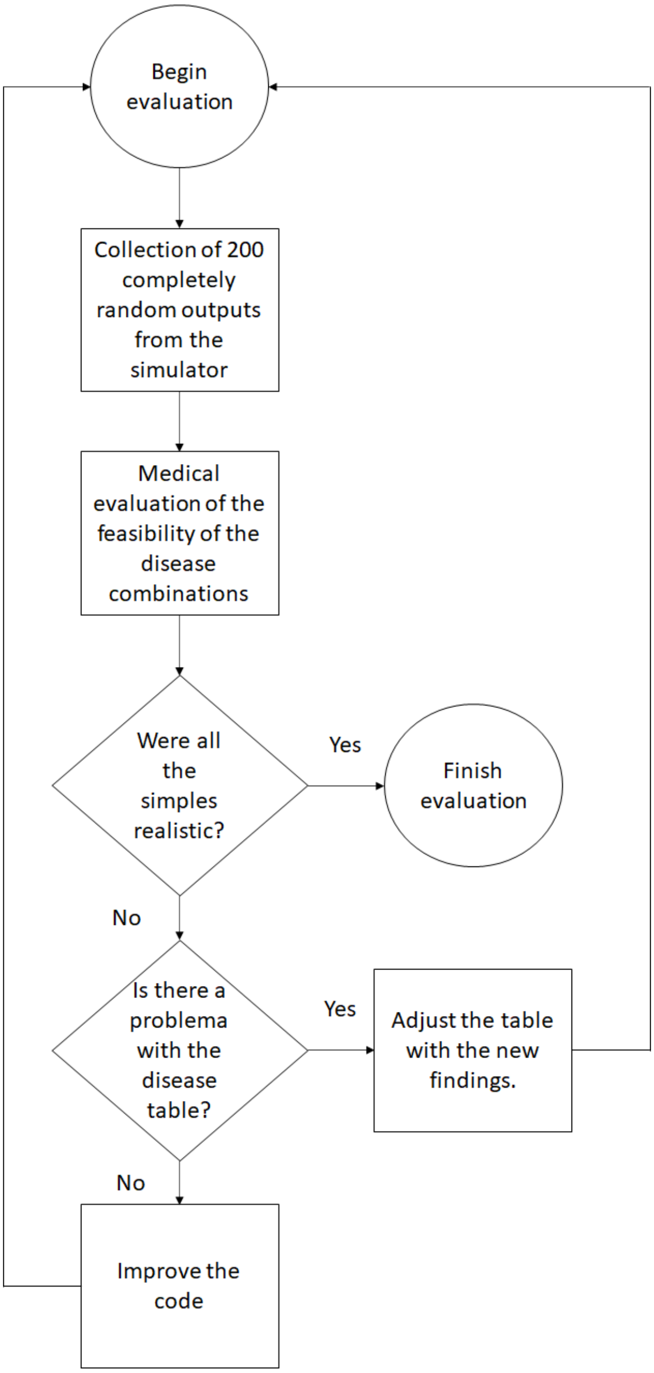


Figure 4. *A diagram of the process of collecting and evaluating data to come with algorithms that only have realistic combinations. A medic evaluated the samples.*

The following code is attached to the left lung. The codes remain the same for the other organs, with the difference that other organs may have different sounds.

```
//For a start, we use the following libraries:
using UnityEngine;
using System;
//The variables are declared
public AudioClip Ressonance;
```

```
public AudioClip Hyperressonance;
public AudioClip Flat;
public AudioClip Dull;
public AudioClip Tympanic;
private float waitTime = 1f;
private float timer = 0.0f;
private Boolean initializerandomsound = false;
private System.Random rng = new
System.Random();
private int selection;
//The Update() method is always running on the
background
private void Update()
{
       timer += Time.deltaTime;
}
//This method runs every time a collision with
the organ with the script attached is
detected.
private void OnCollisionEnter(Collision
collision)
{
       if (initializerandomsound == false)
{
selection = rng.Next(4);
initializerandomsound = true;
Debug.Log(selection);
}
//One second must pass between sounds to avoid
sensitivity issues that would make them sound
several times when the sound should play one
time.
if (timer >= 1)
{
       AudioSource audio =
       GetComponent<AudioSource>();
       audio.volume = 1f;
       String result = ("Left lung percussion:
       );
if (selection == 0)
{
       audio.clip = Ressonance;
       result = result + " Ressonance";
}
else if (selection == 1)
{
       audio.clip = Hyperressonance;
       result = result + " Hyperressonance";
}
else if (selection == 2)
{
       audio.clip = Flat;
       result = result + " Flat";
}
else if (selection == 3)
{
       audio.clip = Dull;
       result = result + " Dull";
}
else if (selection == 4)
{
       audio.clip = Tympanic;
       result = result + " Tympanic";
}
//Changes the audio volume depending on the
collision speed.
audio.volume =
collision.relativeVelocity.magnitude
//Plays the selected audio
audio.Play();
//Records the result on the Unity console
result = result + ", volume: 100%";
Debug.Log(result);
// Check if we have reached beyond 1 second.
if (timer > waitTime)
{
       //Remove the recorded 1 second.
       timer = 0;
}
```

V. THE SIMULATOR

Because of the complexity and the speed of the collisions when percussing, the simulator would cease to function when using the Nvidia PhysX library. The introduction of an experimental physics code called Havok [14], [15] redressed this issue.

Figure 4. *A user is operating the percussion simulator.*

VI. HAPTICS AND PSEUDO HAPTICS

This simulator uses two methods that provide a haptic sensation for the user: 1) pseudo haptics and 2) ultrasound-based haptics. Pseudo haptics is a method that aims to generate a haptic sensation in the user through visual feedback in its most general form. One approach that can make a user ‘feel’ a physical interaction is to present the user with visual feedback. The user’s virtual limbs in a virtual reality environment move differently from how they move in reality. For example, if a user’s virtual hand collides with a virtual object, the pseudo haptics colliders recognise this collision, stop the virtual hand, and prevent any penetration into the virtual object. This approach is powerful, and users ‘feel’ the opposing object’s resistance, albeit only in terms of a sensation.

VII. DISMISSING HAND EXOSKELETONS

Hand exoskeletons such as the Dexmo [16]–[18]or the HaptX can be bulky and uncomfortable. They also come with the usual issues of calibration, common to all robotics devices. And no two hands are identical – finger length and stretch angles for example will all vary. Ultimately, virtual reality users are motivated by comfort and in this respect a system that merely requires a headset will be infinitely more attractive than one that also requires a bulky exoskeleton that needs frequent recalibration and that tends to obstruct and interfere with the percussion procedure.

Figure 5. *(Up) The user tries to palpate the patient, but there are no colliders enabled, so the hand goes through the virtual patient. (Down) The user tries to palpate the patient, but the colliders stop the hands from going through the virtual patient.*

To further enhance the immersive experience within the virtual environment, this simulator also explores ultrasound-based haptics. Ultrasound-based haptics generates a haptic field that the user can experience as a sensation on their hands. The haptic field is generated through an array of ultrasound transducers integrated within a computer-connected device, thereby providing the sensation of touch. Furthermore, the ultrasound field generated by the device can be adjusted to represent the resistance of objects such as spheres and cubes in mid-air above the ultrasound device. The two methods explored enhanced students' virtual reality experience when using the proposed simulator during their studies. Both methods have been shown to be beneficial for percussion.

VIII. CONCLUSIONS

The simulator shows good potential in training students during a pandemic when close contact between people (medics and patients) is potentially risky. From a practical point of view, the proposed system offers a relatively inexpensive solution to training medics in this vital diagnostic field. The Oculus Quest 1 and 2 standalone versions that include hand tracking cost around £300, and there is an intention to include the relevant software. Despite this relative low-cost, the technology behind this human-computer interface immersion system is state-of-the art - indeed very few applications use hand tracking, let alone full-body real-time hand tracking pose and estimation. The software will be called VIRTACH (Virtual Tactile Human), and the intention is to give it away for free through popular virtual reality stores such as Steam and the Oculus store. It was impossible to find a simulator that uses full-body tracking and estimation in real-time with 72 FPS on a regular virtual reality ready laptop.

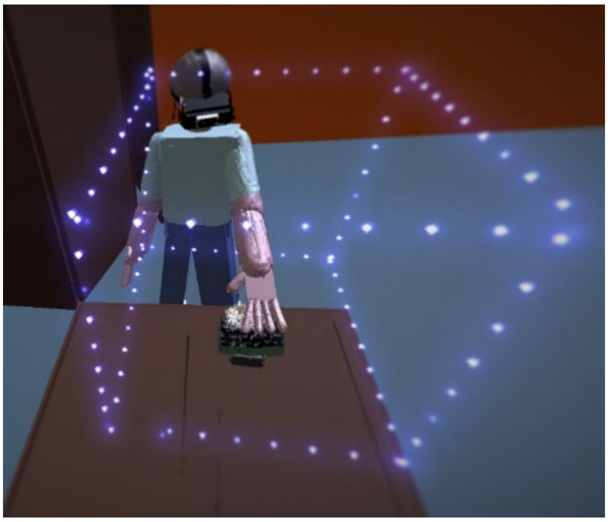


Figure 6. According to the vendor, the best haptic experience is from 20 to 40 cm above the surface of the Ultrahaptics. However, the haptic effect's volume is felt within a cube, with all sides equal to nine Ultrahaptics surfaces, more or less. Image adapted from Google Poly models under the creative commons license.

IX. BIBLIOGRAPHY

[1] J. M. S. Pearce, "Leopold Auenbrugger: Camphor-induced epilepsy - Remedy for manic psychosis," *Eur. Neurol.*, vol. 59, no. 1–2, pp. 105–107, 2007, doi: 10.1159/000109581.

[2] L. Borghi, "Tapping on the chest of history. Lost and found memories of leopold auenbrugger, inventor of percussion, in Austria and beyond," *AMHA - Acta Medico-Historica Adriat.*, vol. 16, no. 1, pp. 127–144, 2018, doi: 10.31952/amha.16.1.6.

[3] M. Mine, "Towards virtual reality for the masses," no. January 2003, pp. 11–17, 2003, doi: 10.1145/769953.769955.

[4] T. British and M. Journal, "On The Recognition Of Enlargements Of The Left Auricle By Percussion , And On Other Clinical Uses Of Dorsal Percussion , Including Percussion Of The Pelvis Author (s): William Ewart Published by : BMJ Stable URL : https://www.jstor.org/stable/20262260," vol. 2, no. 2026, pp. 1167–1170, 2020.

[5] D. L. Clarke, T. M. H. Gall, and S. R. Thomson, "Double jeopardy revisited: Clinical decision making in unstable patients with, thoraco-abdominal stab wounds and, potential injuries in multiple body cavities," *Injury*, vol. 42, no. 5, pp. 478–481, 2011, doi: 10.1016/j.injury.2010.06.027.

[6] A. Murray and J. M. M. Neilson, "Diagnostic percussion: a study of chest-wall motion and the associated tactile sensation," *Med. Biol. Eng. Comput.*, vol. 16, no. 3, pp. 269–273, 1978, doi:

10.1007/BF02442426.

[7] A. Murray and J. M. M. Neilson, “Diagnostic percussion sounds: 1. A qualitative analysis,” *Med. Biol. Eng.*, vol. 13, no. 1, pp. 19–28, 1975, doi: 10.1007/BF02478184.

[8] D. C. Wolf, “Evaluation of the Size, Shape, and Consistency of the Liver,” *Clin. Methods Hist. Phys. Lab. Exam.*, vol. 62, no. 6, pp. 478–481, 1990, [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/21250261.

[9] J. C. Yernault and A. B. Bohadana, “Chest percussion,” *Eur. Respir. J.*, vol. 8, no. 10, pp. 1756–1760, 1995, doi: 10.1183/09031936.95.08101756.

[10] T. British and M. Journal, “Note On Auscultatory Percussion Of The Heart Author (s): Patrick Watson Williams Published by : BMJ Stable URL : https://www.jstor.org/stable/20237240 Tfz BaITIs] OF OF MEDICINF .[NOTE ON AUSCULTATORY PERCUSSION,” vol. 2, no. 1864, pp. 714–715, 2021.

[11] M. O. F. Lung, “THE CANADIAN MEDICAL ASSOCIATION JOURNAL AN IMPROVED METHOD OF LUNG PERCUSSION * TECHNIQUE AND RESULTS OF A CONCENTRATION METHOD OF SPUTUM EXAMINATION *,” pp. 580–581, 1924.

[12] P. P. Roy, P. Kumar, S. Patidar, and R. Saini, “3D word spotting using leap motion sensor,” *Multimed. Tools Appl.*, vol. 80, no. 8, pp. 11671–11689, 2021, doi: 10.1007/s11042-020-10229-5.

[13] K. Gruchalla, “Immersive well-path editing: Investigating the added value of immersion,” *Proc. - Virtual Real. Annu. Int. Symp.*, pp. 157–164, 2004, doi: 10.1109/VR.2004.1310069.

[14] T. Erez, Y. Tassa, and E. Todorov, “Simulation tools for model-based robotics: Comparison of Bullet, Havok, MuJoCo, ODE and PhysX,” *Proc. - IEEE Int. Conf. Robot. Autom.*, vol. 2015-June, no. June, pp. 4397–4404, 2015, doi: 10.1109/ICRA.2015.7139807.

[15] J. Hummel, R. Wolff, T. Stein, A. Gerndt, and T. Kuhlen, “An evaluation of open source physics engines for use in virtual reality assembly simulations,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 7432 LNCS, no. PART 2, pp. 346–357, 2012, doi: 10.1007/978-3-642-33191-6_34.

[16] X. Gu, Y. Zhang, W. Sun, Y. Bian, D. Zhou, and P. O. Kristensson, “Dexmo: An inexpensive and lightweight mechanical exoskeleton for motion capture and force feedback in VR,” *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 1991–1995, 2016, doi: 10.1145/2858036.2858487.

[17] V. Pooryousef, R. Brown, and S. Turkay, “Shape recognition and selection in medical volume visualisation with haptic gloves,” *ACM Int. Conf. Proceeding Ser.*, vol. Vi, pp. 433–436, 2019, doi: 10.1145/3369457.3369508.

[18] “[2016]Dexmo: An exoskeleton for you to touch the digital world - YouTube.” https://www.youtube.com/watch?v=Sif7cY8qwjM (accessed Feb. 18, 2021).