Internship Report

LEVITATING BUTTONS

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Levitating Buttons

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Abstract

The Interact Lab is researching into Human Computer Interactions (HCI) and wanted to carry out a study about levitating buttons. The goal of the internship was to implement acoustic levitation with a device from the firm Ultrahaptics and to capture a mid-air click gesture using a Leap Motion device. The motivation behind it, was to integrate the two in an application. To that end, a Graphic User Interface (GUI) had to be developed in the language of my choice, here C++ with the Qt library. This report presents the entire project, step by step, since the first levitation, to the final GUI and setup.

Résumé

L'Interact Lab, laboratoire de recherche spécialisé en Interactions Homme-Machine (IHM), souhaitait faire une étude sur l'efficacité des boutons en lévitation. Le stage avait pour but de mettre en place une lévitation acoustique grâce à un dispositif de la société Ultrahaptics et de détecter une gestuelle de clique en l'air à l'aide d'une Leap Motion. La motivation derrière cela, était de créer une application incluant les deux. Dans cette optique, une interface graphique devait être implémentée dans le langage de mon choix, ici C++ avec la librairie Qt. Ce rapport présente le projet dans sa totalité, étape par étape, de la première lévitation, jusqu'à l'application et l'intégration finale.

Acknowledgement

This placement was a great experience, extremely rich professionally and personally, much more than I was expecting. For that, I would like to express my very great appreciation to my supervisor, Sriram Subramanian, for this opportunity, for autonomy and confidence he gave me. I also wanted to offer my special thanks to Patricia Cornelio the PhD student I was working with, for this project, and again for the independence I had during my work. I hope the Graphic User Interface I made will help her in the study she will carry out after my departure.

I would like to offer my special thanks to William Frier (PhD Student), for the time he took debugging my code, and explaining me how to code levitations. In the meantime, thanks to the whole Interact Lab members, a really diversified team answering to my questions whenever I had one, in every domain, someone could answer to me. This is a real group , which work in a pleasant atmosphere, helping the team work.

Thanks as well to Sophie Cartier, my IUT supervisor, who put me in touch with Sriram to get this internship and Karine Rouet who helped me a lot to write my cover letter and my CV. Similarly, thanks to all the pedagogic team of the IUT de Bordeaux for all the knowledge they taught me in Computing, Sciences, English and Communication which allowed me to complete my work here.

Finally, thanks to my family and friends for the support, calling me and sending me messages every day.

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Introduction

The Interact Lab is part of The University of Sussex located in Brighton, UK. Sussex campus gathered a lot of research centres from Cognitive Science, to Psychology through Computing. Human Computer Interaction is the main focus of this research lab. Acoustic levitation, Liquid Metal, Haptic technology or Virtual Reality are developed to create new interface types, and explore interactions between human and computer.

The aim of my end-of-course internship here lasting 10 weeks from April 9th to June 15th, was first to improve my English, and also to explore different concepts and cultures. This placement enables me to discover research, a working approach not truly highlighted in France, in an open-minded place where autonomy is the most important.

The project I was working on was focused on acoustic levitation, a whole new principle requiring physics notions I had to fully understand and to appropriate. Acoustic levitation controlling algorithms are currently not entirely handled which shows that it is an important part of the lab's research. The goal was to investigate on levitating interfaces, creating a user study using levitation, motion tracking and haptic feedback. These were combined in order to measure how receptive humans are to this kind of interface. The simplest levitating interface we can do is a button, therefore it is the subject of our research. My job here was to create the entire Graphic User Interface (GUI) in C++ with the Qt Library to measure the human receptivity thanks to the Sense of Agency but also to increase our knowledge about acoustic levitation algorithms.

The first part of this report will present more-in-depth of the campus, the lab, and the major notions that led the project on a theoretical approach. Then in a second part, I will present my involvement in this project and the different jobs I did. These included coding, soldering, designing and motion tracking, with the goal of creating a better GUI.

1. Human-computer interaction or how to improve our world

1.1. Sussex, a leading research-intensive University

Sussex campus

The University of Sussex is a leading research-intensive university near Brighton (£23M expenditure in research). They have both an international and local outlook, with staff and students from more than 100 countries and frequent engagement in community activities and services. It is a really nice place, and a statement of what is the city of Brighton. A peaceful and open minded place, mixing communities and cultures to create a unique city in this country.

Figure 1. University of Sussex

Interact Lab

The Interact Lab of the University of Sussex is a research lab within the School of Engineering and Informatics located in Shawcross Building. The lab is part of the creative technology group and brings together staff, doctoral students and post-graduate researchers from informatics, physics, engineering and design coming from the entire world to pursue research in human-computer interaction. There are also technicians, specialised in 3D printing and laser cutting. The team works with a lot of languages and methods : C++, C# and Java for the developers, Python, MATLAB and COMSOL for the physicists. In the meantime, they use different platform to manage projects. Dropbox is used to share code, sketches, videos or figures. Slack is the principal communication network, allowing private or team discussions. Finally, Trello is also used to plan projects following an Agile software development method.

The recent focus of the interact lab been on creating fog-based displays, acoustic levitation, mid-air haptics and acoustic metamaterials. They want to find new way to interact, to create new application using things people thought impossible and magic. Their researches are funded by both industry and government funding bodies.

Figure 2. Shawcross Building

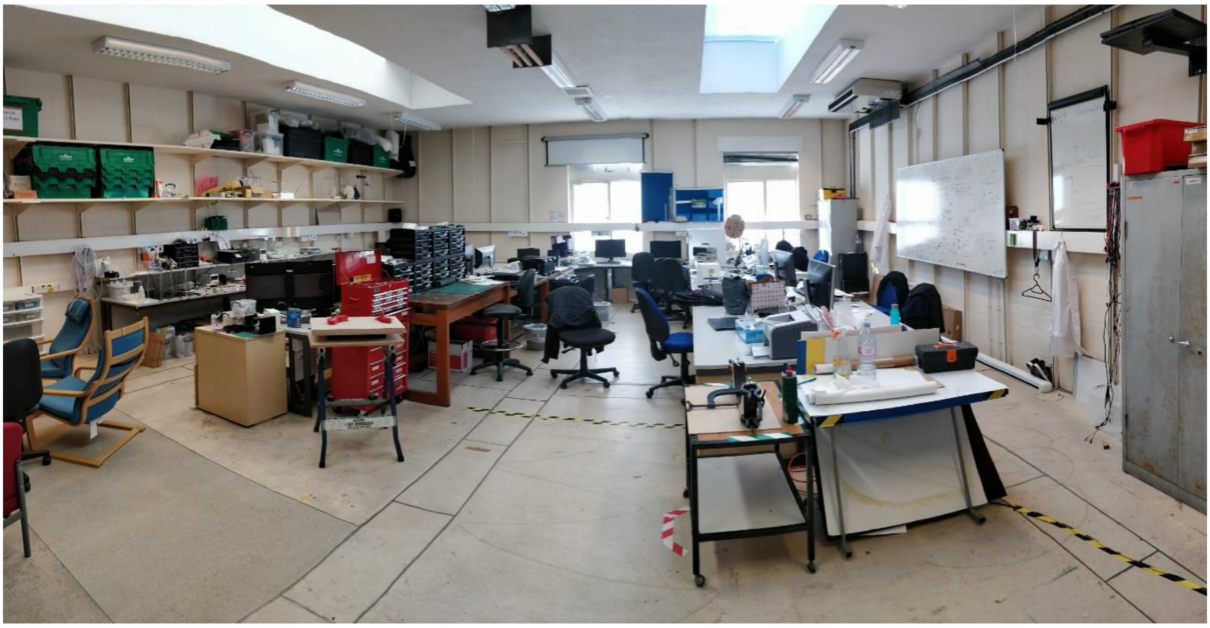


Figure 3. The Interact Lab in Shawcross building

1.2. Ultrahaptics, a new way to interact with computers

The firm

Ultrahaptics is a British company, created in 2013 and based in Bristol, they produce haptic devices. Sriram Subramanian, my supervisor, co-founded the firm. Their breakthrough haptic technology uses ultrasound to create rich, three-dimensional shapes and textures that can be felt, but not seen. This is a new way to interact with machines. With this t new technology, the firm imagine new devices like haptic car dashboard, hob, or computer [5] but also any type of application with that kind of feedback.

Figure 5. Ultrahaptics logo

Figure 6. Haptic car dashboard

Figure 4. Haptic sphere

The device created by the company

The Ultrahaptic board is a device formed of an array of 256 speakers (16x16) called transducers, sending ultrasounds at 40KHz. The first function of the board is to create an haptic feeling. To create this feeling, a different delay is given to each transducers, to make all the signals in the same phase on a precise point.

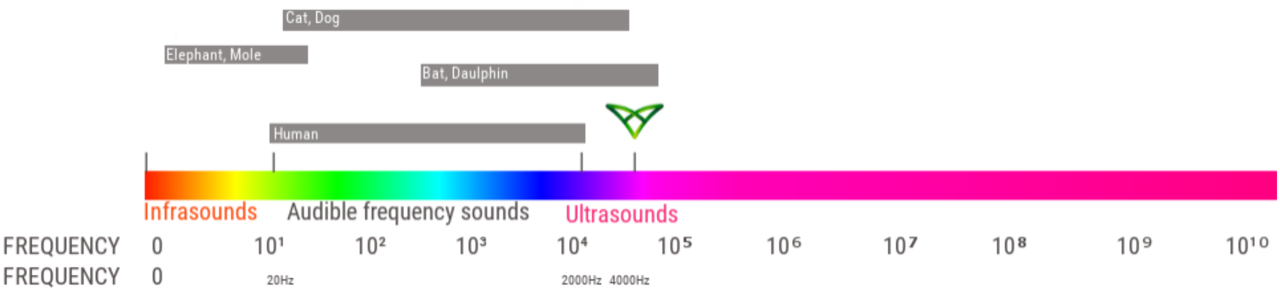


Figure 7. Sounds and their frequency

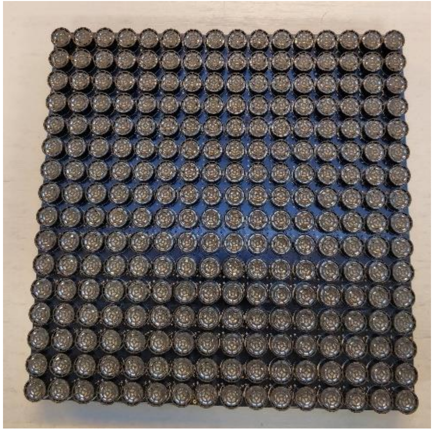
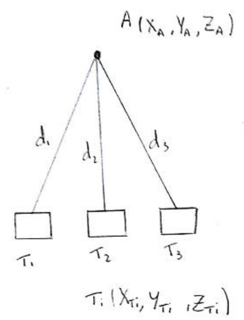


Figure 9. Ultrahaptic Board

Figure 8. Focal Point with the Ultrahaptic Board

Physics involved in haptic feedback



Here is an example of calculating for 3 transducers, but the same method can be extended for a 16x16 array.

To make a focal point (point A), the pressure at this point needs to be maximized. The total pressure (P) is equal to the sum of the pressure created by each transducer (T). To do that, a delay (φ) is applied to the transducers, depending on the distance (d) of it from the focal point and the wave number (k).

$$P_A = P_1 + P_2 + P_3 = e^{-i(kd_1+\varphi_1)} + e^{-i(kd_2+\varphi_2)} + e^{-i(kd_3+\varphi_3)}$$

$$d_i = \sqrt{(X_{Ti} - X_a)^2 + (Y_{Ti} - Y_A)^2 + (Z_{Ti} - Z_A)^2}$$

$$kd_1 + \varphi_1 = kd_2 + \varphi_2 = kd_3 + \varphi_3$$

$$\varphi_i = -kd_i \ (+ m.2\pi)$$

$$m \in \mathbb{Z}$$

$$k = \frac{2\pi}{\lambda}$$

$$\lambda = \frac{c}{f} \quad c \to \text{speed of sound } 343\ m.s^{-1}, \quad f \to 40\ kHz$$

Figure 10. Focal point delays calculation

1.2. Run a study about Sense of Agency

Sense of agency

Patricia Cornelio, the PhD student I'm working with, wrote a scientific article about the Sense of Agency (SoA) [1], [2] . The SoA refers to the subjective experience of voluntary control over actions in the external world. In short, to do an action (like pressing a button), to perceive an outcome (audio, visual, etc …) and to feel you create that outcome. In articles she wrote, she investigated the SoA in touchless systems using the intentional binding paradigm. This consist to add a delay between the action and the outcome and to see when action and feedback are perceived compared to the real timing. The idea was to compare real click and mid-air click. The result was that there is not so much difference between the two which is great for mid-air research. She precise that haptic and auditory feedback help to increase SoA compared with visual feedback in touchless interfaces.

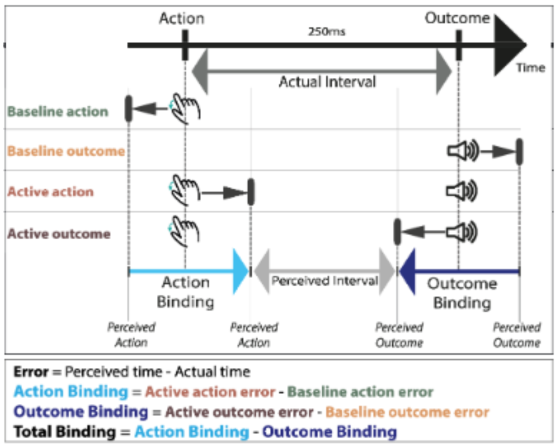


Figure 11. Intentional binding conditions and calculation

My work will consist in creating the User Graphic Interface (GUI) of the new study Patricia is carrying. Now that a mid-air click has been established as an efficient action/input, we want to investigate whether levitating interfaces can be a good feedback/outcome. The simplest interaction we can develop is a levitating button, thus we will need to levitate a particle in order to mimic a physical button.

Acoustic Levitation

There are different ways to produce acoustic levitations. The first one is to use a plane wave and a reflector. By according the sound's frequency with the distance of the reflector, a trap is created. The bead seats in a point where there is no pressure, and next to it, two points where there is a maximum of pressure.

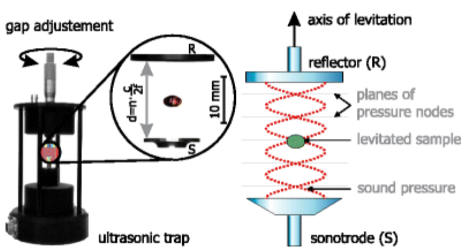


Figure 12. Reflector acoustic levitation

However, this setup is not the best one, it needs a reflector, which is not a good point for the user experience. It is also possible to create a levitation with a Ultrahaptic board and metamaterials, a material engineered to have a property that is not found in nature. This is what Tallulah Gilliard, the previous intern from Bordeaux IUT, worked on.

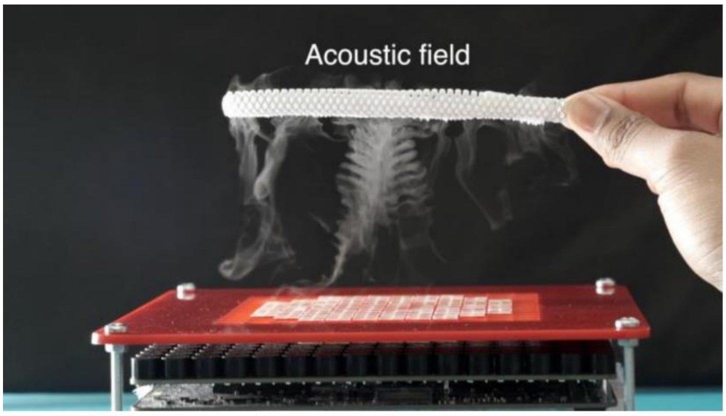


Figure 14. Acoustic field of metamaterial bricks setup

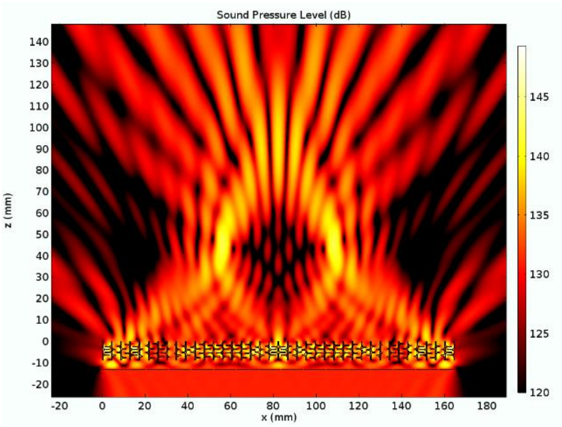


Figure 13. Sound bending pressure profile with a metamaterial bricks array

Here there is a metamaterial bricks array above the Ultrahaptic board. It creates a trap where the bead can seat [3]. On the Figure 14, we can see the sound waves thanks to dry ice, by changing the bricks we can obtain several acoustic profiles. But again, the setup is not convenient, because we can't change the levitation point without stopping the experiment, and changing the metamaterial array.

A scientific article about acoustic levitation [4] shows that there is another way, to create traps by changing the phases of the transducers (same as the haptic system, but with a different signal). There is different traps, the twin trap (also called tweezers)on Figure 15 or the bottle trap (Figure 16), however, these experiment has be done on 20x20 transducers array. The idea, for our study, is to try that on the Ultrahaptic board.

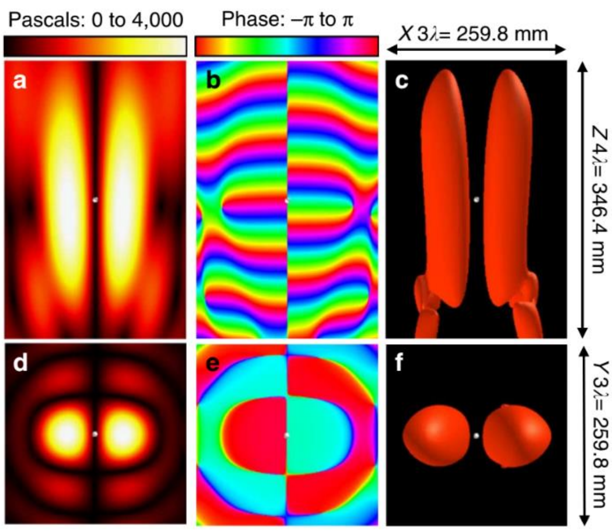


Figure 15. Twin trap pressure, phase, shape profile

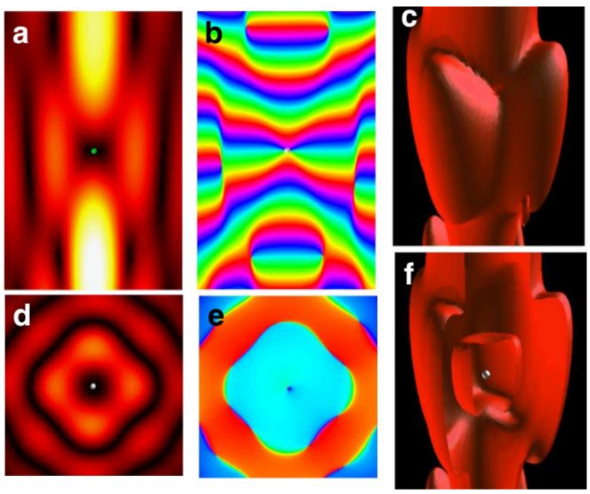


Figure 16. Bottle trap, pressure, phase and shape profile

An important part of my work was first to document myself, through a lot of scientific articles wrote by members of the lab or from other Universities. Different researchers, coming from Germany, Japan or UK carry out conferences to present their work. The aim is to collect a lot of knowledge and to be aware of the research drive elsewhere. In the lab, every week, a member was presenting his work (Figure 17.), to get everybody involved in it in the same mind. This is only after documenting myself a lot, that I started to think about the GUI I had to implement.

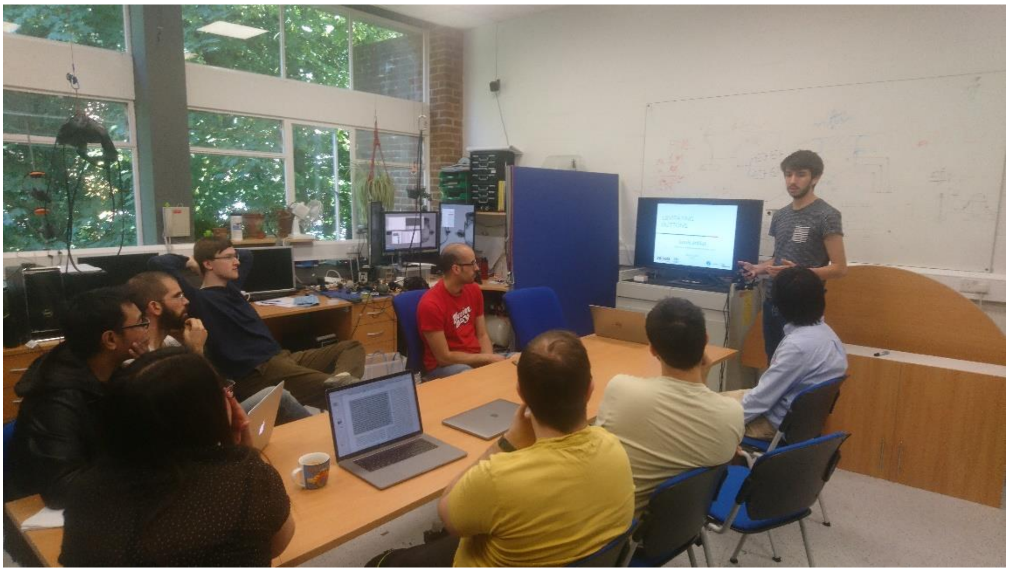


Figure 17. "Reading Group" presentation

2. Implementation of the user study

2.1. The Graphic User Interface

A study divided into different parts

This experiment is composed into 3 different blocks. Now we know that a mid-air click is a good action for Sense of Agency. The goal is to know if a levitating application can be used. The approach is to measure the sense of Agency linked to the simplest object, a button. We also need to compare it with a classic interface, that's why I implemented a block where the feedback is on the screen. There is 2 levitating feedback, with a click in front of the button, and above it. The feedback is a button pressed, on screen with pictures or with a levitating bead going up and down (Figure 18). Thus the participant will perform a click gesture in mid-air, it will be an up-down finger movement of about 2cm. After the action and a 250ms delay, the participant will perceive the different outcomes.

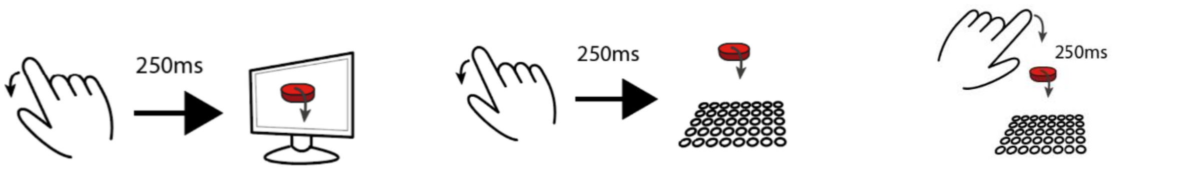


Figure 18. Study 3 different blocks

In these 3 blocks, and as shown in Figure 19 there are 4 conditions within each blocks. In the meantime, each conditions contains 30 occurrences. First, we want to know how the user reacts to the experiment, that's why the two first instructions are just baseline action and outcome. (Action without outcome and the opposite). Then the user perceived the outcome after clicking. Moreover, to collect different data, the block order is mixed.

Table 1. Study pattern

Between Blocks Rand	Within Block
1 ON-SCREEN	1 - [B_action] 2 - [B_outcome] 3 - [A_action] 4 - [A_outcome]
2 IN FRONT	1 - [B_action] 2 - [B_ outcome] 3 - [A_action] 4 - [A_ outcome]
3 ABOVE	1 - [B_action] 2 - [B_ outcome] 3 - [A_action] 4 - [A_ outcome]

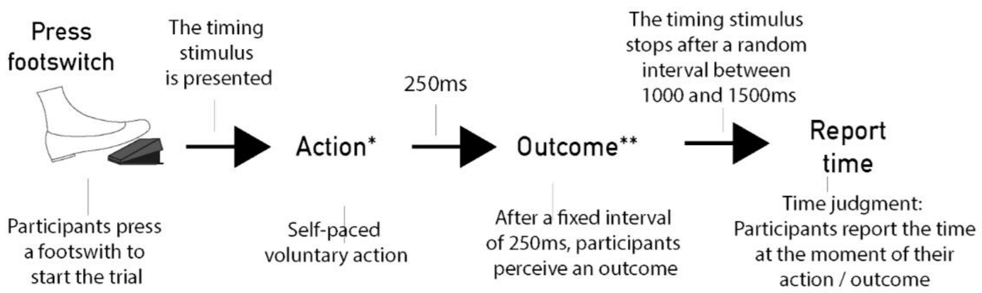


Figure 19. Single trial pattern

A trial begin with a press on the footswitch, then the user can do the action whenever he wants, and after a delay of 250ms, the outcome is created. Finally he needs to report the time corresponding to the within block (action or outcome). **Before each within block, a picture explain what the participant needs to focus on. However, to do this report, we need to find a way to**

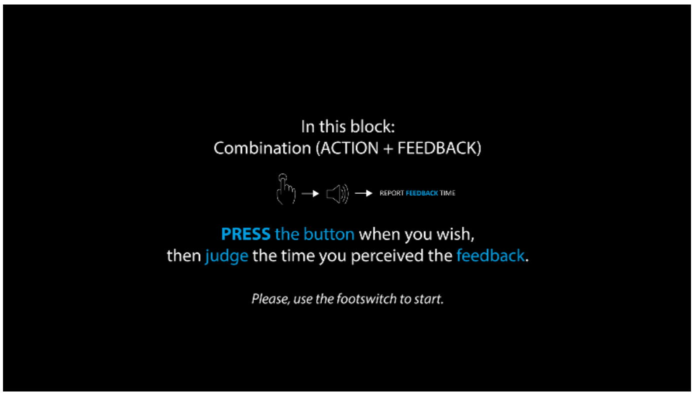


Figure 20. Instruction for a within block

A way to measure the Sense of Agency

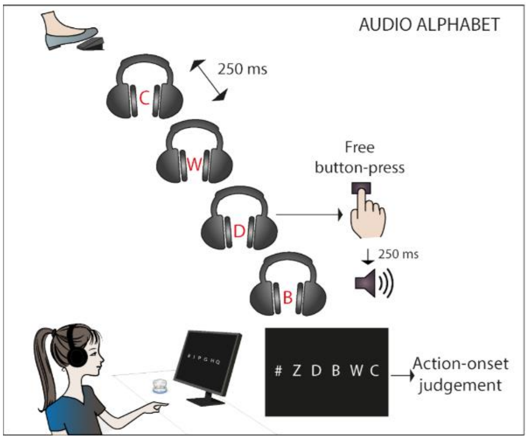


Figure 21. Audio alphabet sketch

Patricia Cornelio already did that type of study, and also carry out on to compare the different way to measure sense of agency [1]. The visual or audio alphabet is two famous methods. We will use the Audio Alphabet method, which is the best one for this particular study. Indeed, in our case, the user needs to be focused on the levitation. So the participants will be presented an unpredictable stream of letters via pre-recorded voice using headphones with frequency of 250ms (The Visual alphabet is the same system with letters displayed on screen). After each trial, participants will be asked to report the letter they heard at the moment of their action/outcome. Participants will be shown a response mapping with five options corresponding to the letter shown during the actual action/outcome (0-back), two letters immediately before (1-back & 2-back) and two letters immediately after (1- forward & 2-forward). An additional option will be given (# symbol) in case that any of the letters shown corresponded to their answer, i.e., the perceived time was larger than 2-back/2-forward. In this case we discard that trial.

To calculate Intentional binding, the errors are calculated as the difference between the reported and actual time, based on the consonant timing presentation. When the "error" time is between -125 and 125, the letter chosen by the user was the good one. A csv file is edited with the results to analyse it (Annexe 4).

2.2. Different devices integrated in this study

Motion tracking with the Leap motion

Figure 22. Leap Motion device

The Leap Motion is a motion tracking Virtual Reality (VR) device created by the firm Leap Motion Inc, founded in 2010. This sensor device supports hand and finger motions as input, without requiring hand contact or touching. The SDK features a C-style API which can be used directly in a C program, or integrated in Unity or Unreal. There is also older version for C++, C#, Java, JavaScript, Python, etc .. but are available but no longer actively supported. To detect a simple click , the C++ version is enough.

To implement a click (Annexe 1), first I talked with a few people in the lab to get ideas. The logic of first implementation was to use the middle finger as a reference, comparing the position of the Distal Interphalangeal joint (DIP joint) of the index with the major. However, with the click had to be executed with at least the major out straight. So then I compared the DIP Joint with the Metacarpophalangeal joint (MCP joint) of the index. I added the notion of speed to check that there is a movement for the click and not only the click position.

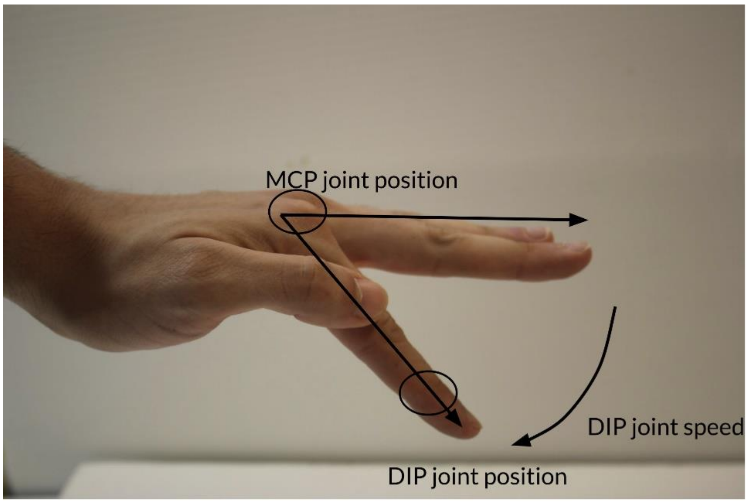


Figure 23. Mid-air click diagram

The Ultrahaptic board to create my levitation

The simplest way to create a levitation with one board is to try to create a tweezer/twin trap. This trap is quite simple to create. To create this trap, first I had to create a focal point. The calculation is the same as the haptic focal point. There is a maximum pressure at this point. To create the twin trap, instead of a maximum pressure point, we need a point where there is a minimum of pressure. To do that, I added π to the phases of half of the board. Half of the board now has opposite phases. This create a minimum pressure point, with around, two big pressure points, which constitute the tweezers (Figure 25).

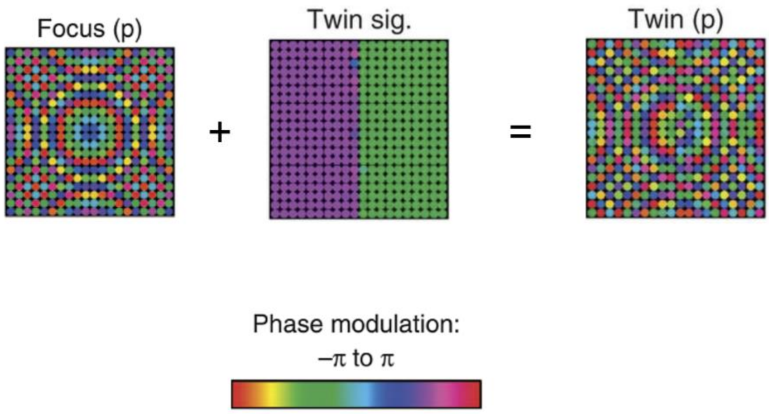


Figure 24. Tweezer trap phases explanation

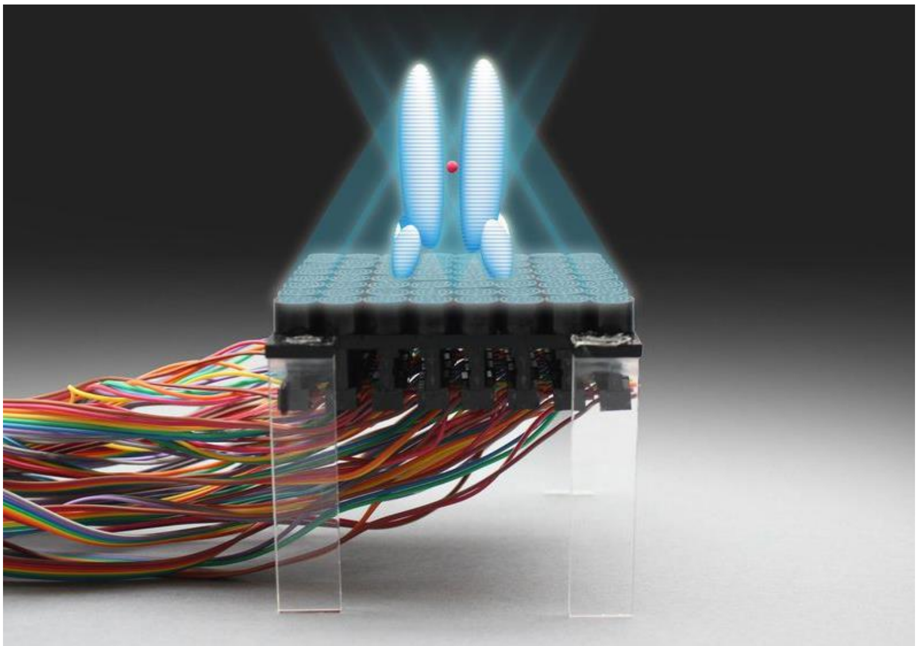


Figure 25. Tweezer trap sound wave representation

This is the theoretical way to create a tweezer trap, however there is difference between physics and coding. Indeed, the delay is negative in physics instead of being positive in computing, 2 ways of thinking understandable but, this was something which took time do debug (Annexe 3).

Another thing that we didn't knew is the height of the focal point. The trap cannot be up to 8cm and to trap the bead the better is the lower. The bead was popping out every time but we didn't really knew why. So we all started to think about it, to find a solution, for 2 or 3 hours. Afterwards we looked to the trap with dry ice, in order to see sound waves. The trap was here, so I tried several position, to finally settled the trap at 3.5 cm.

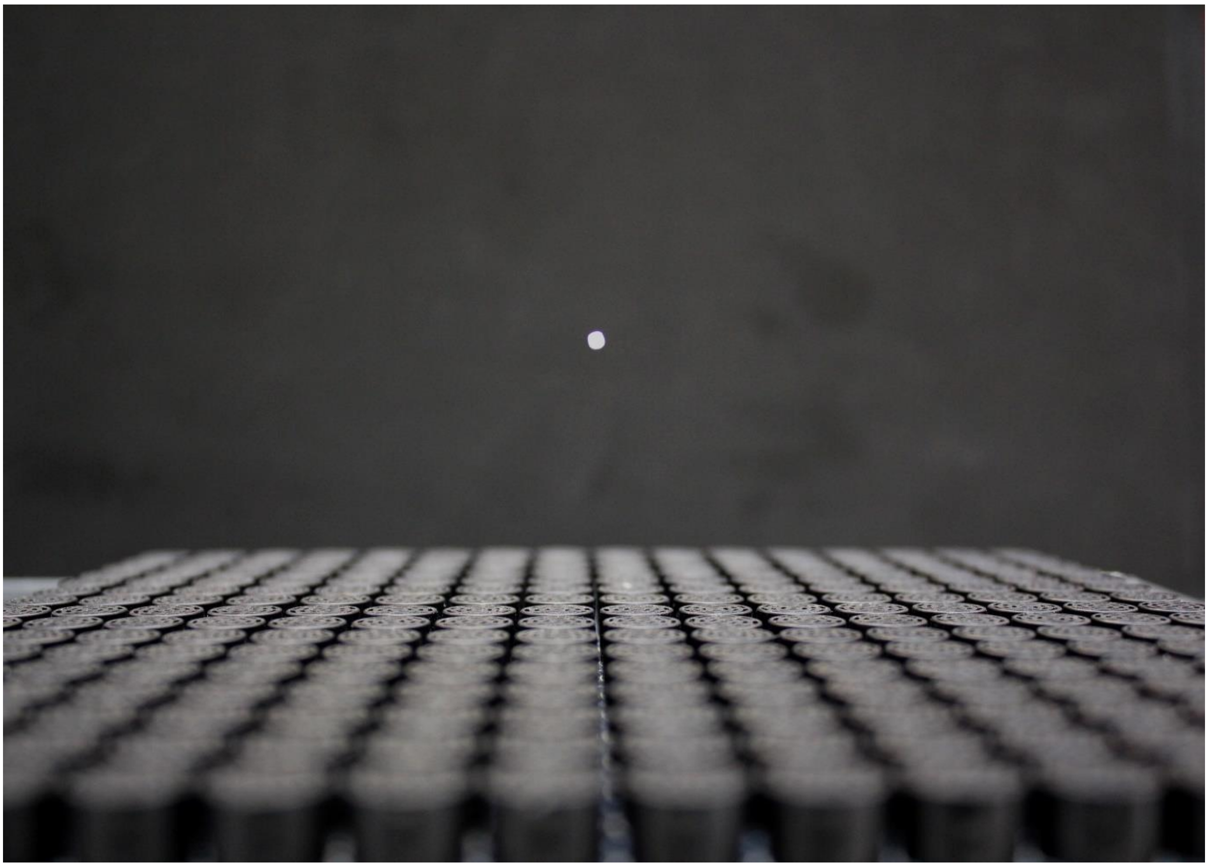


Figure 26. Acoustic levitation, using a tweezer trap

Afterwards, another intern implemented a new way to create levitation, thanks to a program permitting to create any shapes. So we tried different traps, vortex trap, bottle trap and others. However, for this study we choose the twin trap, because the button was more realistic with this one.

Once I succeed this first levitation I had to implement the button system. The good point is that we just needed to lower/upper the focal point (Figure27), to make the tweezer calculation and the bead is following the trap (Annexe 2).

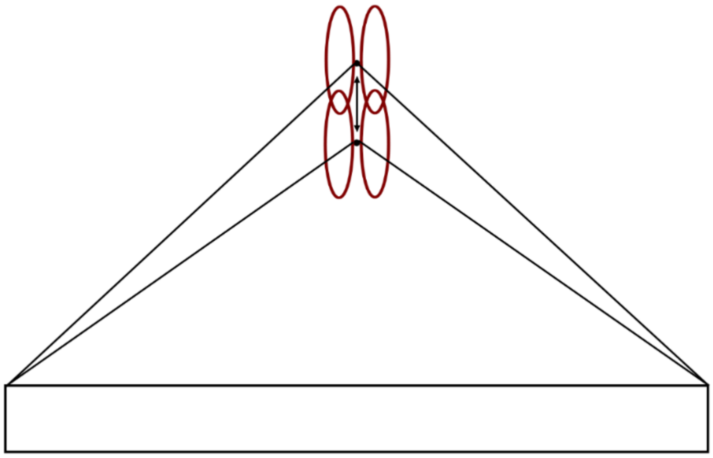


Figure 27. Twin trap click representation

The major problem of this levitation is that it uses at lest 10 or 12 rows of transducers. For the above click, we wanted to add an haptic feedback, in order to increase the user experience, and maybe to obtain a better sense of agency. But the 4-6 rows remaining are not enough to create a good haptic feedback. So the hardware, limited our ambitions

2.3. Final setup

Solve the overheating problem

One of the major issue using this board is the overheating. Indeed, the board receives data over and over again, which warms it a lot, instead of receiving it just when the phases are updated. The study is supposed to contain 2x30 minutes of levitation, but after a levitation of 2 minutes the board temperature is approximately 50 °C, on minute later it comes up to 60°C. Even if the transducers can theoretically resist to 85°C, the levitation is

Figure 29. 3D printed first cooling system

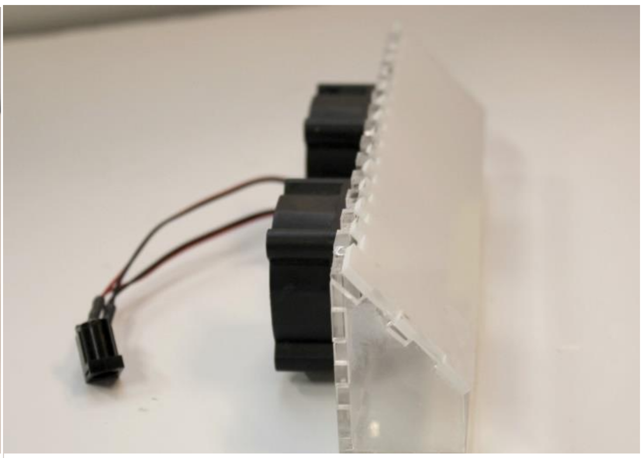


Figure 28. Laser cut second cooling system

troubled by the heat. The bead is popping out the trap, or the board can simply stop. We tried to found a software way to solve this problem, but we cannot improve the amount of data send to the board, because we doesn't control it, so we have an hardware limitation. Actually, the board is originally created for haptic feedback, which is really different : levitation requires all the transducers on, every single time. So we decided to try different ways to cool the board. The first idea was to use a 3D printed system (Figure 28), to cool the board from below.

With 6 minutes levitation, it was not enough so we decided to take a system which cool it from inside (Figure 29) , between the two cards of the board. These fans were not powerful so I designed the same system, with much powerful fans (Figure 30) . With this one, we succeed 30min levitation without trouble. We also put tape on the side to guide the air flow. When the GUI implementation was done, the new laser cut technician did a final version of this cooling system, to obtain something more professional (Figure 31).

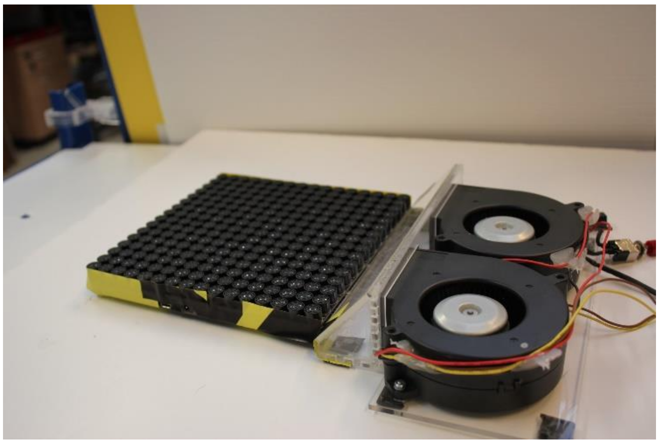


Figure 30. Cooling system I designed

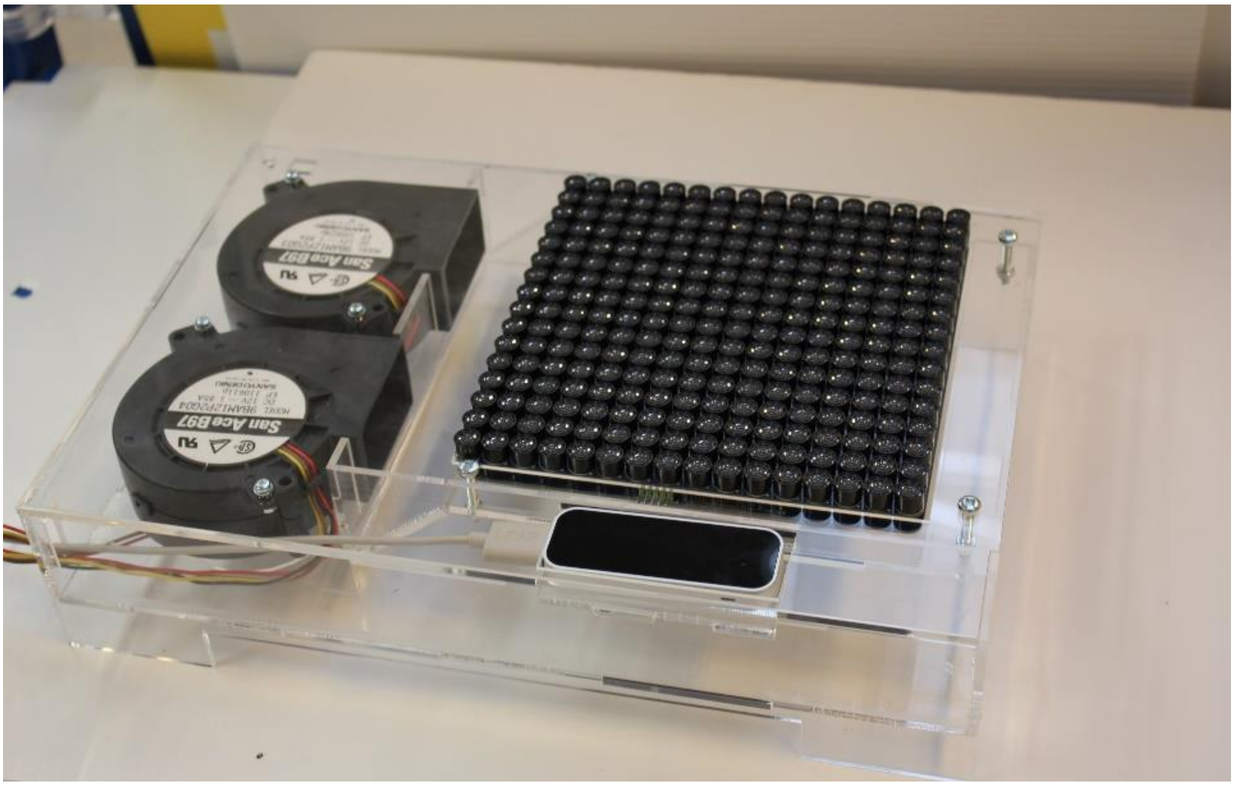


Figure 31. Final cooling system

To go further

One of the goal of the internship was also to improve our knowledge about acoustic levitations. With a Ultrahaptic board we succeed a 4 bead levitation (Figure 33) in the meantime, with the optimization phases attribution program of my colleague, which was totally amazing and unexpected. In the meantime, we tried with another board (Figure 32), made by an other member of the lab. The results were really promising, however, there is only one in the lab, that is not dedicated to this project.

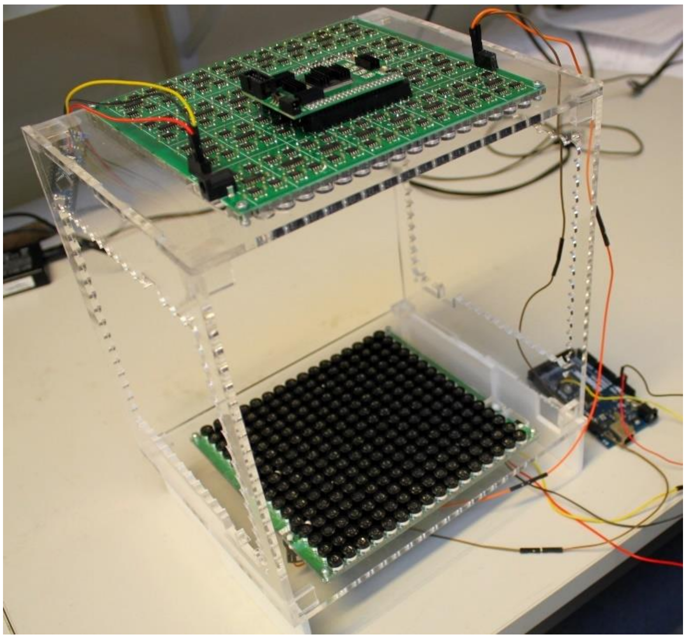


Figure 32. Double board levitating system

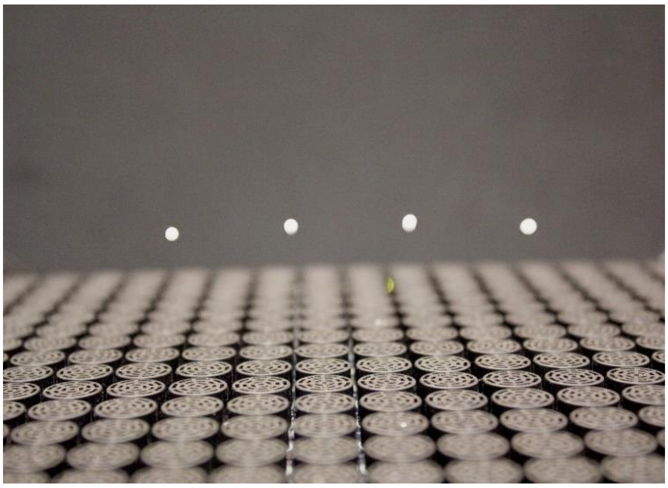


Figure 33. Four bead trapped

Conclusion

The study will be carried out by Patricia Cornelio in a few weeks, if the results are positive, they will imagine different levitating interfaces, much more complete than a simple click on a button. But for this a different hardware needs to be used. The final goal is to implement pattern with multiple beads, and my colleagues are exploring different ways like projecting light on the particle. We also wanted to add an haptic feedback on the levitating button to increase the Sense of Agency but the board was the limitation.

I finished this project on time, even if there is an integration to do on different operating systems. The planning in the lab is not really defined, because it deals with researching, but I had to deliver the user study at the end of the ten weeks.

In any case, this project was a success, I carry out the tweezer trap levitation within two weeks, which also helped the team in different projects, based on the Ultrahaptic board. Moreover, my work has been limited by the hardware, indeed, this board is not the one to use for more advanced levitations, but it really helps to understand more how the board works. That's why, in the next month, a new board is going to be built.

In the meantime, I really learnt a lot during these 2 months, in debugging, building projects, using different libraries, re-discovered C++ but also in the way of thinking. I had to do a code that everybody can understand, use and modify. I also learnt a bit about soldering, designing and 3D printing or laser cutting when I participated to build the different cooling systems.

I really enjoyed the team work here, everybody is available to help each of us which is really appreciable. I really loved this experience here, and it seems to be mutual because I am coming back in July to continue the project and to implement more acoustic levitations.

Annexes

Annexe 1 - Mid-air click tracking, using the Leap library

```cpp
void ClickListener::onConnect(const Controller& controller) {
    _connected = true;
}

void ClickListener::onDisconnect(const Controller& controller) {
    _connected = false;
}


void ClickListener::onFrame(const Controller& controller) {
    const Frame frame = controller.frame();
    FingerList allFingers = frame.fingers();
    Finger indexFinger;

    for (FingerList::const_iterator fl = allFingers.begin(); fl != allFingers.end(); fl++)
        if ((*fl).type() == Finger::TYPE_INDEX)
            indexFinger = *fl;                // store the index

    // store 1st & 3rd joint position and speed
    int yDIPpos = (int)indexFinger.jointPosition(Finger::JOINT_DIP).y;
    int yMCPpos = (int)indexFinger.jointPosition(Finger::JOINT_MCP).y;
    int yindexSpeed = (int)indexFinger.tipVelocity().y;

    if (yDIPpos != 0 && _clickAuthorized)          //if there is a hand detected and the experiment manager authorized the click
    {
        if (yindexSpeed < _speedThresold && yMCPpos - yDIPpos > _phalanxYThresoldMax)       //Check the speed and the difference between 1st & 3rd joint position with the use of the speed
        {
            _click = ClickState::DOWN;
            _clickTime = std::chrono::system_clock::now();      // store the time point of the click for the anduio manager
            _clickMotion = true;
        }
        else if (_clickMotion &&  yMCPpos - yDIPpos < _phalanxYThresoldMin) //check if the 2 joints are close in y
        {
            _click = ClickState::UP;
            _clickMotion = false;
        }
    }
    else
        _click = ClickState::NO_HAND;
}
```

The class ClickListener is used to detect the mid-air click. The method onFrame is called perpetually since the leap is connected.

Annexe 2 - Phases calculations for a twin/tweezer trap & button implementation

```cpp
void BoardManager::tweezer() {
    //distance calculation between each transducer and focal point
    for (int x = 0; x < UH_grid; x++)
        for (int y = 0; y < UH_grid; y++)
            distanceArray[x][y] = sqrt(pow(_spacing*x - _Xa, 2) + pow(_spacing*y - _Ya, 2) + pow(-_Za, 2));

    //tweezer calculation
    //Here we can see that the formula is k*distance, it should be -k*d but the UH function do not like it.
    for (int x = 0; x < UH_grid; x++)
        for (int y = 0; y < UH_grid; y++)
            if (y < UH_grid / 2)
                deltaPhi[x][y] = _k * distanceArray[x][y];
            else
                deltaPhi[x][y] = _k * distanceArray[x][y] + M_PI;

    //linear translation
    for (int x = 0; x < UH_grid; x++)
        for (int y = 0; y < UH_grid; y++)
            _options.linearDeltaPhi[y + x * UH_grid] = deltaPhi[x][y];
}

void BoardManager::addZ(double value) {
    _Za += value;
    tweezer();
}

void BoardManager::button(double amplitude, int buttonDuration, int delay, bool mockClick) {
    if(!mockClick) //because there is no delay needed during a mock click
        this_thread::sleep_for(chrono::duration<int, milli>(delay));    //250ms delay
    addZ(-amplitude);    //down
    this_thread::sleep_for(chrono::duration<int, milli>(buttonDuration));    //wait
    addZ(amplitude);    //up
}
```

This function calculation calculate the trap depending of the point position (Xa,Ya,Za) of the focal point. We can see that the equation is k*distance instead of -k*distance, because the Ultrahaptic function makes the conversion.

Annexe 3 - Ultrahaptic Board's transducers phase attribution, using the Ultrahaptics library

```
void emission_callback(SEmitter& emitter, SInterval& interval, const Ultrahaptics::HostTimePoint& deadline, void* user_ptr)
{
    // Get our options structure to check what we should be doing
    BoardManager::callback_options* options = static_cast<BoardManager::callback_options*>(user_ptr);
    // For each point in time that this callback is populating data for...
    for (auto it = interval.begin(); it != interval.end(); ++it)
    {
        // Clear all transducer data, to ensure no transducers are active when they shouldn't be
        it->state().setZero();
        // If we should be turning a transducer on...
        if (options->is_outputting)
        {
            // Set the chosen transducer's activation state to be fully on
            for (size_t i = 0; i < options->current_size; i++)
            {
                for (size_t j = 0; j < options->current_size; j++)

                {
                    int size = ((options->current_size - 2) / 2);
                    int idx = getID(i, j, size);
                    int transducer_index = get_transducer_idx(i, j, size);

                    it->state().complexActivationAt(idx) = complex<float>(cos(options->linearDeltaPhi[transducer_index]), sin(options->linearDeltaPhi[transducer_index]));


                }

            }
        }

    }
```

This method is also call indefinitely. The ID of the transducers are made for an electronic aspect, following a cores, ports and pins logic, which is not useable for computing. A function is called to convert the ID.

Annexe 4 - Study (5 trials) csv result

	A	B	C	D	E	F	G	H	I	J
1		TimingType :								
2		AudioTiming								
3										
4		Block	Within Bloc	Trial		Action	Feedback	Report	Error	
5										
6		ON-SCREEI	Baseline Ac	1		7006		6950	-56	
7		ON-SCREEI	Baseline Ac	2		4050		3933	-117	
8		ON-SCREEI	Baseline Ac	3		10281		10228	-53	
9		ON-SCREEI	Baseline Ac	4		2693		2653	-40	
10		ON-SCREEI	Baseline Ac	5		2269		2399	130	
11										
12		ON-SCREEI	Baseline Oı	1			3032	3157	125	
13		ON-SCREEI	Baseline Oı	2			2023	2148	125	
14		ON-SCREEI	Baseline Oı	3			1262	1387	125	
15		ON-SCREEI	Baseline Oı	4			2016	2141	125	
16		ON-SCREEI	Baseline Oı	5			1520	1645	125	
17										
18		ON-SCREEI	Active Acti	1		2768		2651	-117	
19		ON-SCREEI	Active Acti	2		3454		3420	-34	
20		ON-SCREEI	Active Acti	3		2503		2403	-100	
21		ON-SCREEI	Active Acti	4		1728		1645	-83	
22		ON-SCREEI	Active Acti	5		6224		6191	-33	
23										
24		ON-SCREEI	Active Out	1			3648	3911	263	
25		ON-SCREEI	Active Out	2			1847	2149	302	
26		ON-SCREEI	Active Out	3			5034	5172	138	
27		ON-SCREEI	Active Out	4			3013	3149	136	
28		ON-SCREEI	Active Out	5			2671	2902	231	
29										
30		IN FRONT	Baseline Ac	1		3516		3662	146	
31		IN FRONT	Baseline Ac	2		3465		3658	193	
32		IN FRONT	Baseline Ac	3		2683		2653	-30	
33		IN FRONT	Baseline Ac	4		1483		1139	-344	
34		IN FRONT	Baseline Ac	5		1132		1136	4	
35										
36		IN FRONT	Baseline Oı	1			3535	3404	-131	
37		IN FRONT	Baseline Oı	2			3279	3150	-129	
38		IN FRONT	Baseline Oı	3			3784	3654	-130	

Glossary

Sense of Agency (SoA) : subjective awareness of initiating, executing, and controlling one's own volitional actions in the world.

Virtual Reality (VR) : is an artificial environment that is created with software and presented to the user in such a way that the user suspends belief and accepts it as a real environment. The major part of the feedbacks currently used are sounds and vision, but it can deal with every type of perception.

Acoustic Levitation : method for suspending matter in a medium, using intense soundwaves.

Motion capture : process of recording the movement of objects or people.

Human Computer Interaction (HCI) : Tools and methods used in order to allow human to communicate with computers/machines.

Metamaterial : material engineered to have a property that is not found in nature.

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Web pages

http://interact-lab.com/about-us/

http://www.sussex.ac.uk/about/