

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

MASTER THESIS

---

# **Ensuring self-haptic Consistency for Immersive Amplified Embodiment**

---

*Author:*  
Sidney BOVET

*Supervisor:*  
Dr. Ronan BOULIC

*Submitted in fulfillment of the requirements  
for the degree of MSc in Computer Science*

*in the*

Immersive Interaction Group  
School of Computer and Communication Sciences

January 10, 2017

*“Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism.”*

Dave Barry

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

# *Abstract*

Computer Science Section  
School of Computer and Communication Sciences

MSc in Computer Science

## **Ensuring self-haptic Consistency for Immersive Amplified Embodiment**

by Sidney BOVET

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...



## *Acknowledgements*

The acknowledgments and the people to thank go here...



# Contents

<b>Abstract</b>	<b>iii</b>
<b>Acknowledgements</b>	<b>v</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Stroke Rehabilitation . . . . .	1
1.1.1 Motivation . . . . .	1
1.2 Motion Capture . . . . .	1
1.3 Psychometrics . . . . .	1
<b>2 Related Work</b>	<b>3</b>
2.1 Motion Capture and Inverse Kinematics . . . . .	3
2.1.1 Egocentric Coordinates . . . . .	3
2.2 Stroke Rehabilitation . . . . .	3
<b>3 Implementation</b>	<b>5</b>
3.1 Distortion model . . . . .	5
3.2 Egocentric Coordinates . . . . .	7
3.3 Reachable Sphere . . . . .	7
<b>4 Experiment</b>	<b>9</b>
4.1 Just Noticeable Difference . . . . .	9
4.2 Hypothesis . . . . .	9
4.3 Equipment and Software . . . . .	9
4.4 Experiment design . . . . .	9
4.4.1 Task . . . . .	10
4.4.2 Procedure . . . . .	10
4.5 Subjects . . . . .	11
<b>5 Results and Discussion</b>	<b>13</b>
5.1 Main Section 1 . . . . .	13
5.1.1 Subsection 1 . . . . .	13
5.1.2 Subsection 2 . . . . .	13
5.2 Main Section 2 . . . . .	13
<b>6 Conclusion</b>	<b>15</b>
6.1 Main Section 1 . . . . .	15
6.1.1 Subsection 1 . . . . .	15
6.1.2 Subsection 2 . . . . .	15
<b>A Questionnaires</b>	<b>17</b>
A.1 Characterization . . . . .	17
A.2 Redirection detection . . . . .	17
A.3 Embodiment . . . . .	17
<b>B Results</b>	<b>19</b>





# 1 Introduction

Foreword: will cover multiple subjects from stroke rehabilitation to motion capture.

## 1.1 Stroke Rehabilitation

Explanation of what a stroke is and how to recover.

### 1.1.1 Motivation

Emphasis on the motivation being a key aspect of the rehabilitation process.

As argued by [1], the more a patient participates to a rehabilitation task the greater the motor recovery will be. Keeping participants motivated during such tasks is thus essential.

## 1.2 Motion Caputre

The action of capturing one's movements and possibly altering it, be it in order to fit it onto an avatar of different moprphology or to change aid one reaching a target.

## 1.3 Psychometrics

JND and other PM concepts.



## **2 Related Work**

### **2.1 Motion Capture and Inverse Kinematics**

Reference to [2] and [3].

#### **2.1.1 Egocentric Coordinates**

More details on [3].

### **2.2 Stroke Rehabilitation**

Stroke rehabilitation techniques and research.



## 3 Implementation

In this chapter we describe how we adapted the preexisting motion capture software in order to obtain the desired distorted behaviour.

### 3.1 Distortion model

As briefly mentioned in chapter 2, we are taking advantage of the Egocentric Coordinate formalism in order to introduce our distortion model. We are modifying each relative displacement vector as specified in Equation 3.1 according to a function that we are going to detail in the next few lines.

For ease of experimentation and understandability, we are looking for a linear function  $f(x) = ax + b$ . Figure 3.2 gives an example of what we aim to achieve, while Figure 3.1 below gives a more mathematical point of view of the distortion we are looking for, especially in terms of  $a$ , the slope of the function. This plot, as well as all of the other plots of this report, were obtained using the Plotly API [4].

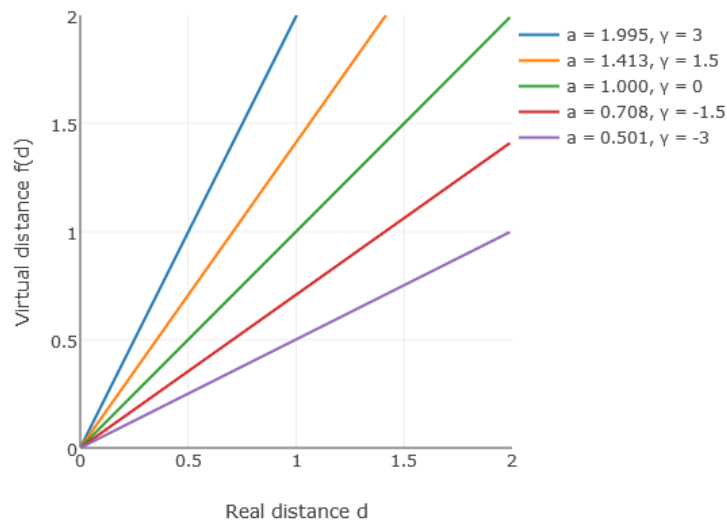


FIGURE 3.1: An example of a few distortion functions for various values of slope  $a$  and gain  $\gamma$ .

First of all we want to preserve self-haptic contacts. Such contact happens when a relative displacement vector  $\mathbf{v} = \mathbf{0}$ , which means that we need  $f(0) = 0$ , and thus  $b = 0$ .

Intuitively, the slopes should be arranged around 1 which we want to correspond to a gain of  $\gamma = 0$ . One can also figure out that there is a correspondance between slopes below and above the line  $f(x) = x$ . For instance, for a given virtual distance to cover, a slope of 0.5 makes

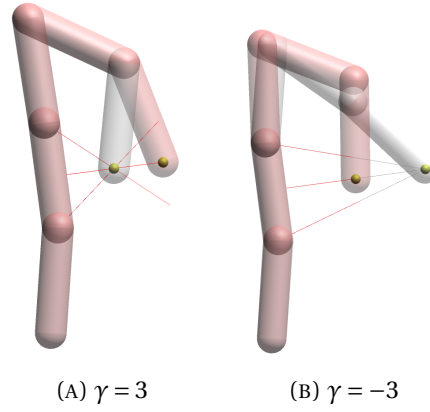


FIGURE 3.2: Two examples of distortion applied to a simple IK arm with multiple segments. The gray lines are the relative displacement vectors and the red ones are their distorted counterparts.

the traveling distance twice as long, whereas a slope of 2 halves the required movement.

Formally, we modify each relative displacement vectors  $\mathbf{v}_i$  according to a gain  $\gamma$  measured in dB. A distorted position  $\mathbf{p}_j$  is thus obtained using equation 3.1, which has been obtained by modifying the definition proposed by [3]:

$$\mathbf{p}_j = \sum_{i=1}^n \hat{\lambda}(\mathbf{x}_i + f(\mathbf{v}_i, \gamma)) \quad (3.1)$$

And  $f$  is defined as:

$$f(\mathbf{v}, \gamma) = \hat{v} \cdot \|\mathbf{v}\| \cdot 10^{\frac{\gamma}{10}} \quad (3.2)$$

Where  $\mathbf{v}$  is a vector,  $\hat{v}$  is its normalized counterpart, and  $\gamma \in \mathbb{R}$ . The last factor,  $10^{\frac{\gamma}{10}}$ , comes from the definition of a gain, in dB [5], based on two values  $P_1$  and  $P_2$  of a single, yet undefined unit:

$$\begin{aligned} \text{gain} = \gamma &= 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right) \\ \frac{\gamma}{10} &= \log_{10}(\text{slope}) \\ \text{slope} &= 10^{\frac{\gamma}{10}}. \end{aligned}$$

A value of  $\gamma = 3$  thus indicates that the virtual movement will roughly be twice the amplitude of the registered one ( $1.995 \approx 2$ ), while a gain of  $\gamma = -3$  means one will have to travel twice as big ( $0.501$ ) as a perceived distance in order to cover it. Figure 3.2 shows two examples of distortion, and Figure 3.1 gives a few instances of distortion functions with varying  $\gamma$  values.

### Other Functions

Before deciding to use a simple, thus easier to quantify, linear function for our experimentation process, we tried out different functions that we think are of interest for further applications. Two of these functions are described here as a reference for further investigation.

Description and plots of the Power and Cosine functions.

### 3.2 Egocentric Coordinates

We added a slight modification to the definition of the position proposed by [3], namely the one we modified to obtain Equation 3.1, and more precisely the way  $\lambda$  is defined. As explained in Appendix A.4 of [6], it is originally computed as the product of two importance factors, proximity and orthogonality respectively denoted  $\lambda_p$  and  $\lambda_{\perp}$ .

Given that the justification for the latter factor mainly relies on the semantic information it conveys, and considering that it would introduce complex behaviors in the distortion, we decided to remove it. As an example, having the hand at a given distance of the belly and changing only its orientation with respect to that body part would cause that hand's position to be affected differently by other nearby body parts and thus be altered by our distortion model.

The former importance factor was initially defined as  $\lambda_p = \frac{1}{\|\mathbf{v}\|}$ . In practice we find that this formula does not give enough importance to nearby body parts, and we decided to change it slightly as  $\lambda_p = \frac{1}{\|\mathbf{v}\|^2}$ , which more closely represents the amount of surface of an object that is visible at a distance  $\|\mathbf{v}\|$ .

### 3.3 Reachable Sphere

A few words on the concept of reachable sphere and how it might help at the limits of the reachable space.





## 4 Experiment

We are trying to estimate the limits of self attribution of a distorted movement and will do so by estimating the just noticeable difference (JND) in visual stimuli discrepancy. This means estimating the just noticeable distortion made to the movement and hence the visual stimuli. The JND is estimated by using the adaptive staircase method introduced by [ref].

This method tries to estimate the JND by finding an upper and a lower bound for that value. These are found by changing the intensity of the distortion, based on whether the subject judged the last trial as distorted or not, and the JND is computed as the mean of the last few staircase turns (i.e. going from an increasing trend to a decreasing one or vice-versa). The decision judgment is gathered using a Yes/No prompt called the detection question : "Did the movements you saw exactly correspond to the movements you performed?"

### 4.1 Just Noticeable Difference

The JND will be measured in term of  $\gamma$ , the gain of the distortion function, Equation 3.2. In general, if  $\gamma = -3$  the subjects are hindered by having to travel two times the distance between the targets, whereas if  $\gamma = 3$  the movement will be amplified and the required motion will be reduced by 50%.

Due to the nature of the Egocentric Coordinates and how the distortion is applied (respectively detailed in Chapters 2 and 3), this will not exactly be a metric of the difference in the distance that the subjects have to cover in order to reach the target, such as the metric used by [ref to Henrique]. It however gives a good understanding of the strength and the effect of the applied distortion.

### 4.2 Hypothesis

The hypothesis we have for the experiment is the following:

H1 The absolute value of the JND will be higher when the distortion is positive.

### 4.3 Equipment and Software

The HMD used for this experiment is the Oculus Rift in its first consumer version, with a resolution of  $0 \times 0$  pixels per eye and a refresh rate of 90 Hz. Some more words on head and body tracking, with references to Eray's paper [ref].

### 4.4 Experiment design

We manipulate two factors: the sign of the distortion (positive or negative), respectively yielding a helped and hindered movement, and the starting position of the task (chest of leg). See chapter 3 for a complete overview of the concept of distortion and its sign.

We consider the starting position as a factor because of the nature of the distortion, which causes horizontal movements to be slightly more distorted. This is due to the proximity of many chest-located reference points as opposed to only four leg segments, thus having the sum of all relative displacement vectors diverting the hand position in the forward direction.

#### 4.4.1 Task

While the whole set of IK goals will be distorted during the experiment, we will be focusing on the dominant hand movement. The task is performed in a seated position in order to avoid any unnecessary movement of the lower limbs, and has the subjects reach three successive target, one of which is in the air in front of them, and the two others are located at various locations on their skin. The reaching task is performed with the directing hand, and the subjects are instructed to keep their other hand at their side.

The first target T1 to be displayed is one on the skin and requires the subjects to perform a self-contact in order to activate it. After a random time between 200 and 300 ms, the target activates. The position of the air target T2 is then computed such that the subjects have to move a predefined distance  $d = 50$  cm between T1 and T2, as well as between T2 and T3 once the air target is reached. This is achieved by computing the intersection between the two spheres of radius  $d$  centered on T1 and T3, and choosing the topmost position. A more detailed explanation of how this is achieved can be found in chapter 3.

One experiment run consists of a reaching task, followed by the detection question. Based on the answer to this question, the experiment software modifies the distortion as follows:

"Yes"                      The discrepancy is increased.

"No" and  $\gamma \neq 0$       The discrepancy is decreased.

"No" and  $\gamma = 0$       The parameter is not changed, given that this would invert the sign of the distortion.

The amount of each increment or decrement is dynamic: it starts at 0.1 and is halved after the first staircase turn. That value is then kept for the rest of that staircase. The staircase is completed either when the subjects change direction 7 times or when they performed 20 trials in that staircase.

#### 4.4.2 Procedure

The subjects are welcomed and introduced to the protocol described here, and then introduced to the tracking equipment. A characterization form is then filled in by the subjects during this first part of the experiment, with background questions regarding any previous VR experiment or experience with HMDs. They are then asked to remove their shoes and to wear the motion capture suit. A calibration is then performed as described by [ref to Eray's paper].

Before beginning the actual staircase trials, a familiarization phase takes place. The subjects briefly interact with the virtual environment without any distortion, so that they correctly embody the avatar and understand the question process.

More on the next steps later.

## **4.5 Subjects**

A few physical limitations will be applied to filter the subjects of this experiment. They will be required to be right-handed for ease of software development, and will need to be both smaller than 180cm and have an body mass index between 18 and 27. The latter is due to our motion capture equipment and especially the suit on which the markers are placed.

We also require that they have a normal or corrected to normal vision, and be fluent in both written and spoken english.



## 5 Results and Discussion

### 5.1 Main Section 1

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam ultricies lacinia euismod. Nam tempus risus in dolor rhoncus in interdum enim tincidunt. Donec vel nunc neque. In condimentum ullamcorper quam non consequat. Fusce sagittis tempor feugiat. Fusce magna erat, molestie eu convallis ut, tempus sed arcu. Quisque molestie, ante a tincidunt ullamcorper, sapien enim dignissim lacus, in semper nibh erat lobortis purus. Integer dapibus ligula ac risus convallis pellentesque.

#### 5.1.1 Subsection 1

Nunc posuere quam at lectus tristique eu ultrices augue venenatis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aliquam erat volutpat. Vivamus sodales tortor eget quam adipiscing in vulputate ante ullamcorper. Sed eros ante, lacinia et sollicitudin et, aliquam sit amet augue. In hac habitasse platea dictumst.

#### 5.1.2 Subsection 2

Morbi rutrum odio eget arcu adipiscing sodales. Aenean et purus a est pulvinar pellentesque. Cras in elit neque, quis varius elit. Phasellus fringilla, nibh eu tempus venenatis, dolor elit posuere quam, quis adipiscing urna leo nec orci. Sed nec nulla auctor odio aliquet consequat. Ut nec nulla in ante ullamcorper aliquam at sed dolor. Phasellus fermentum magna in augue gravida cursus. Cras sed pretium lorem. Pellentesque eget ornare odio. Proin accumsan, massa viverra cursus pharetra, ipsum nisi lobortis velit, a malesuada dolor lorem eu neque.

### 5.2 Main Section 2

Sed ullamcorper quam eu nisl interdum at interdum enim egestas. Aliquam placerat justo sed lectus lobortis ut porta nisl porttitor. Vestibulum mi dolor, lacinia molestie gravida at, tempus vitae ligula. Donec eget quam sapien, in viverra eros. Donec pellentesque justo a massa fringilla non vestibulum metus vestibulum. Vestibulum in orci quis felis tempor lacinia. Vivamus ornare ultrices facilisis. Ut hendrerit volutpat vulputate. Morbi condimentum venenatis augue, id porta ipsum vulputate in. Curabitur luctus tempus justo. Vestibulum risus lectus, adipiscing nec condimentum quis, condimentum nec nisl. Aliquam dictum sagittis velit sed iaculis. Morbi tristique augue sit amet nulla pulvinar id facilisis ligula mollis. Nam elit libero, tincidunt ut aliquam at, molestie in quam. Aenean rhoncus vehicula hendrerit.



## 6 Conclusion

### 6.1 Main Section 1

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam ultricies lacinia euismod. Nam tempus risus in dolor rhoncus in interdum enim tincidunt. Donec vel nunc neque. In condimentum ullamcorper quam non consequat. Fusce sagittis tempor feugiat. Fusce magna erat, molestie eu convallis ut, tempus sed arcu. Quisque molestie, ante a tincidunt ullamcorper, sapien enim dignissim lacus, in semper nibh erat lobortis purus. Integer dapibus ligula ac risus convallis pellentesque.

#### 6.1.1 Subsection 1

Nunc posuere quam at lectus tristique eu ultrices augue venenatis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aliquam erat volutpat. Vivamus sodales tortor eget quam adipiscing in vulputate ante ullamcorper. Sed eros ante, lacinia et sollicitudin et, aliquam sit amet augue. In hac habitasse platea dictumst.

#### 6.1.2 Subsection 2

Morbi rutrum odio eget arcu adipiscing sodales. Aenean et purus a est pulvinar pellentesque. Cras in elit neque, quis varius elit. Phasellus fringilla, nibh eu tempus venenatis, dolor elit posuere quam, quis adipiscing urna leo nec orci. Sed nec nulla auctor odio aliquet consequat. Ut nec nulla in ante ullamcorper aliquam at sed dolor. Phasellus fermentum magna in augue gravida cursus. Cras sed pretium lorem. Pellentesque eget ornare odio. Proin accumsan, massa viverra cursus pharetra, ipsum nisi lobortis velit, a malesuada dolor lorem eu neque.





# A Questionnaires

All the questions used will be displayed here.

## A.1 Characterization

The characterization questionnaire

## A.2 Redirection detection

The yes/no question

## A.3 Embodiment

The embodiment questionnaire



## B Results

Results will be fully shown here.



# Bibliography

- [1] E. Flores, G. Tobon, E. Cavallaro, F. I. Cavallaro, J. C. Perry, and T. Keller, “Improving patient motivation in game development for motor deficit rehabilitation”, in *Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology*, ACM, 2008, pp. 381–384.
- [2] E. Molla and R. Boulic, “Singularity free parametrization of human limbs”, in *Proceedings of Motion on Games*, ACM, 2013, pp. 187–196.
- [3] E. Molla, H. Galvan Debarba, and R. Boulic, “Egocentric mapping of body surface constraints”, *TCG*, 2017.
- [4] P. T. Inc. (2015). Collaborative data science, [Online]. Available: <https://plot.ly>.
- [5] *Ieee 100 : The authoritative dictionary of ieee standards terms*. New York: Standards Information Network, IEEE Press, 2000, ISBN: 0738126012.
- [6] E. Molla, “Precise and responsive performance animation for embodied immersive interactions”, PhD thesis, Ecole Polytechnique Fédérale de Lausanne, 2016.