ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

MASTER THESIS

Ensuring self-haptic Consistency for Immersive Amplified Embodiment

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"*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 Coputer and Communication Sciences

MSc in Computer Science

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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…

This project explores the possibility of distorting movements in the context of a stroke reabilitation task presented as a target-reaching VR serious game.

Acknowledgements

The acknowledgments and the people to thank go here…

Contents

Abstract **iii**

Acknowledgements **v**

1 Introduction **1**
1.1 Stroke Rehabilitation 1
1.2 Virtual Reality 1
1.2.1 Immersion, Embodiment, and Presence 2
Immersion 2
Presence 2
Embodiment 2
1.2.2 Haptics and Self-haptics 2
1.3 Motion Capture 2
1.4 Amplified Embodiment 3
1.5 Serious Games 3

2 Related Work **5**
2.1 Motion Capture and Inverse Kinematics 5
2.1.1 Egocentric Coordinates 5
2.2 Stroke Rehabilitation 5

3 Implementation **7**
3.1 Distortion model 7
3.2 Egocentric Coordinates 9
3.3 Reachable Sphere 9

4 Experiment **11**
4.1 Just Noticeable Difference 11
4.2 Hypothesis 11
4.3 Equipment and Software 11
4.4 Experiment design 11
4.4.1 Task 12
4.4.2 Procedure 12
4.5 Subjects 13

5 Results and Discussion **15**
5.1 Main Section 1 15
5.1.1 Subsection 1 15
5.1.2 Subsection 2 15
5.2 Main Section 2 15

6 Conclusion **17**
6.1 Main Section 1 17
6.1.1 Subsection 1 17
6.1.2 Subsection 2 17

A Questionnaires **19**
A.1 Characterization 19
A.2 Redirection detection 19
A.3 Embodiment 19

B Results **21**

Bibliography **23**

1 Introduction

In order to properly introduce this project we need to briefly cover multiple subjects, ranging from stroke rehabilitation to motion capture techniques. All these seemingly different subjects revolve around the idea that we can do something to help stroke patients recover faster by having them participate to serious Virtual Reality (VR) games in which their movements are distorted to keep them motivated.

1.1 Stroke Rehabilitation

As explained by [1], a stroke is a medical condition occuring when parts of the brain stop being provided with proper blood flow. Without such oxygenation, brain cells quickly die. The resulting brain damage may induce various symptoms, such as loss of vision to one side or paralysis. It is the latter that is of interest to us, and more precisely the motor recovery process involved after the stroke itself has been identified and treated. As exposed by [2], there were more than 10 million stroke cases in 2013, which represents an increase of around 60-75% with respect to 1990.

The motor recovery process invlolves so-called constraint-induced movement therapy, a technique that is at least 100 years old and was proposed by [3]. It takes advantage of neuroplasticity and involves movement exercises of the paralysed limb. The more the movements are exercised the better the motor recovery will be.

The process as a whole is a long one, involving checkups and exercises at both the hospital and home. Many factors play a role in how successful the recovery process will be, one of them and maybe the most important one being motivation. As argued by [4], 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 Virtual Reality

We now jump to a completely different topic, but a careful reader will quickly understand how both are closely linked and of interest to us.

Vitual Reality can be defined as “The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.” [5] The most common type of VR device used nowadays are Head-Mounted Displays (HMD), wich are constructed as a screen in front of which two lenses are fixated, allowing the device to be held in front of the eyes while focusing the screen’s content at infinity. Coupled with inertial sensors, such device allows one to look around at a virtual environment. Other VR displays also exist, such as the CAVE: a cube with screen-faces surrounding a user proposed by [6]. In the recent days, companies such as Oculus VR and HTC have begun comercializing HMD and VR becomes more widespread than ever.

1.2.1 Immersion, Embodiment, and Presence

As VR becomes more and more accessible to the general public and broadly used in the industry, immersion tends to be generally accepted as a term describing all of the following concepts.

Immersion

Immersion however has a clear definition offered among others by [7], [8] that we think is preferable to be recalled here: it refers to the capability of a system to deliver a convincing set of sensory stimuli. It is an objective measurment of parameters such as screen resolution, audio equipement, and sensors used.

Presence

What most people tend to call immersion actually is the sense of presence, described by [9], [10] as the "sense of being there". As explained by [11], the central concept of the state of presence is that despite *knowing* that it is a simulation, the user *acts in* and *reacts to* the virtual environment as if it were real.

Embodiment

Embodiment is defined in the field of cognitive neuroscience and philosophy of the mind by [11], [12], and encompasses the relevance of sensorimotor skills and the role the body has in shaping the mind, as well as the subjective experience of using and 'having' a body. It is formally defined by [13] as follows: "E is embodied if some properties of E are processed in the same way as the properties of one's body".

One may from that perspective embody a tool, such as a pen or a hammer, even though that tool is not considered as being part of one's body. As described by [13], the *sense* of embodiment (SoE) refers to the fact that one *feels* such phenomena as opposed to only *knowing* that it exists. As an example, learning that an organ is part of our body makes us embody that organ even though we cannot feel it, whereas felling like the tip of our pen actually is part of our hand creates a SoE towards that pen.

1.2.2 Haptics and Self-haptics

'Haptic' relates to the sense of touch, and more specifically to the one associated to manipulating objects. Feeling the pressure of a sphere between one's fingers when grasping a ball is a haptic feedback. Self-haptic similarly denotes the haptic feedback of touching one's own body part. The feedback thus is dual: by touching one's own arm the brain will receive both the information of the hand touching something and the arm being touched by something. Moreover, before the contact even occurs the brain predicts such self-contact using proprioceptive information about the position of both body parts in space, and is thus very sensitive to such feedback inconsistency.

1.3 Motion Capture

Motion capture can be defined as the action of capturing one's movements in order to reproduce such a motion in one context or another. Video game animations for instance are often performed by actors, whose walking or fighting movements are catured and then played back on the game's characters. The captured movement is often slightly altered, e.g. in order to fit it onto an avatar of different moprphology, as proposed by [14].

1.4 Amplified Embodiment

The concept of amplified embodiment can easily be understood as the merging of both section 1.2.1 and 1.3. By capturing one's movements and transposing those on an avatar, we may create a SoE towards that avatar. The goal of amplified embodiment is to distort that avatar's movements by amplifying them while preserving the SoE, which might be partially or completely lost if the distortion is too heavy ornon-continuous for instance.

1.5 Serious Games

To conclude this chapter we take a look at another distinct topic, one that closes the loop and creates a connection betwenn stroke rehabilitation, VR, motion capture, and amplified embodiment.

As defined by [15], [16], a serious game is a game that neither has entertainment, enjoyment, nor fun as its primary purpose. Instances of serious games include educational ones such as [17], a 1988 video game where young children could learn the alphabet by exploring a house with a yellow, egg-shaped character and playing various mini games, or the more recent [18], which is a running mobile application using storytelling coupled with geolocalization to keep people motivated at running outside.

We hope that by now the thread linking all of the above subjects is clear enough: we are interested in discovering by how much we can distort one's movements in the context of a VR serious game aimed at motor recovery while altering the sense of embodiment as little as possible, with the goal of keeping the patients motivated at performing the rehabilitation task.

2 Related Work

2.1 Motion Capture and Inverse Kinematics

Reference to [19] and [14].

2.1.1 Egocentric Coordinates

More details on [14] and [20].

2.2 Stroke Rehabilitation

Stroke rehabilitation techniques and research. Talk about [4] and others.

3 Implementation

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

3.1 Distortion model

Linear Function

As briefly mentioned in chapter 2, we are taking advantage of the Egocentric Coordinate formalism in order to introduce our distortion model. We modify each relative displacement vectors $\mathbf{v}_i$ according to some value γ. A distorted position $\mathbf{p}_j$ is thus obtained using equation 3.1, wich has been obtained by modifying the definition proposed by [14], using a function that we are going to detail in the next few lines.

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

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 [21].

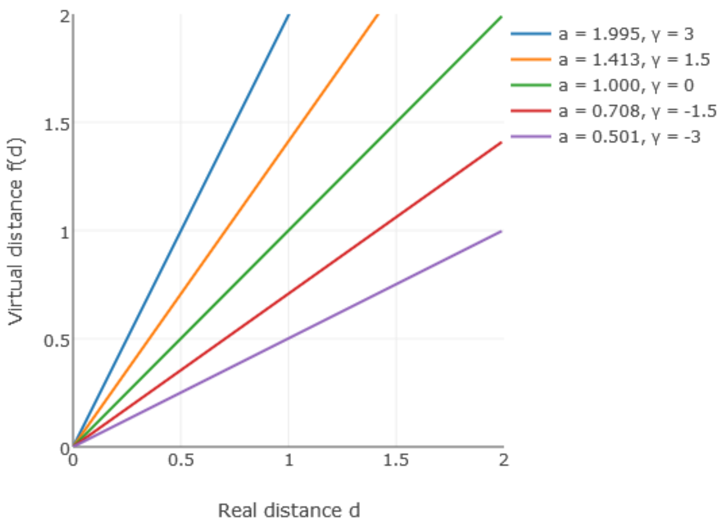
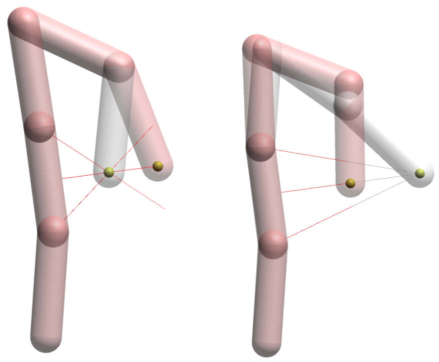


FIGURE 3.1: An example of a few distortion functions for various values of slope a and gain γ.



(A) $\gamma = 3$ (B) $\gamma = -3$

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. Similarly, the gray arm represents the pose the real arm would take whereas the red one shows the resulting distorted pose.

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 correspong to $\gamma = 0$. 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 the traveling distance twice as long, whereas a slope of 2 halves the required movement.

Formally, we are modifying each relative displacement vector as specified in Equation 3.1, with γ representing a gain, measured in dB, and f defined as:

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

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 [22], 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 γ 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 one more modification to the definition of the position proposed by [14] which we modified to obtain Equation 3.1, and more precisely the way λ is defined. As explained in Appendix A.4 of [20], it is originally computed as the product of two importance factors, proximity and orthogonality respectively denoted λ_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 chest 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 $\lambda_p = \frac{1}{\|\mathbf{v}\|^2}$. –Mention angle solide.–

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 discrepency. 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 dection 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 γ, 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 x 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 $d = 50\,\text{cm}$ 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 chosing 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 staicase 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 developement, 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

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5.1.1 Subsection 1

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6 Conclusion

6.1 Main Section 1

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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.

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