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Development of a Natural VR User Interface Using Haptic Gloves

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Dresden, August 19, 2020

Task Description

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I hereby declare that I wrote this thesis on the subject

Development of a Natural VR User Interface Using Haptic Gloves

independently. I did not use any other aids, sources, figures or resources than those stated in the references. I clearly marked all passages that were taken from other sources and cited them correctly.

Furthermore I declare that – to my best knowledge – this work or parts of it have never before been submitted by me or somebody else at this or any other university.

Dresden, August 19, 2020

Lucas Waclawczyk

Kurzfassung

abstract text german

Abstract

abstract text english

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1 Introduction

2 Development

2.1 Devices and Software

For the purpose of thesis, I used a pair of haptic gloves called Avatar VR which is a registered trademark of NeuroDigital Technologies, S. L., referred to as ND hereafter. The company's details can be found at `neurodigital.es`.

To use the Avatar VR on a computer, one needs to download, install and run the ND Suite. This program provides a background service and GUI for managing and accessing the devices. A connection can be established via Bluetooth after which all sensor data is graphically accessible from the GUI.

ND also supplies a developer's API in the form of three files (`NDAPI.h, NDAPI_x64.lib and NDAPI_x64.dll` or `x86` respectively) which need to be included into the respective project in a suitable manner. A singleton of the `NDAPI.h` can be instanstiated and used to access the data of devices connected to ND Suite.

Additionally, a Vive tracker was used to determine the user's hand position and orientation. The Avatar VR can be mechanically connected to the tracker using a coupling, that needs to be acquired separately. The devices named so far and the way of coupling them can be seen in figure 2.1.

The foundation for the graphics software I developed is given by the `cgv` framework provided by the chair of computer graphics and visualization at TU Dresden.

A user can view the plugin on a computer screen with the `cgv_viewer` or on a Vive head mounted device (HMD) simply by connecting one to computer.

2.2 Project Idea and Structure

When developing a VR user interface, the first question is: what is it supposed to do? To give it some context rather than just moving boxes, I decided to design it as a conn panel on the USS Voyager (Star Trek). The term *conn* is short for *control and navigation*, so the panel is used to stear the ship. The classes used to implement this and their interaction are shown in figure 2.2.

The main class and entry point carries the same name as the plugin itself. It is derived from the `cgv` classes

(a) Uncoupled devices, colors mark coupling point

(b) Coupled devices on user hand

Figure 2.1: Devices used to track the user's hand: Vive tracker, coupling, Avatar VR

`base`, `drawable`, `event_handler` and `provider`, and used for management of all objects. Its capability to handle `vr_pose_events` is used to forward tracker poses (position and orientation) to the `hands` and HMD poses to the `head_up_display`. It distributes `draw()` commands among the relevant members and manages the calibration routine described in section 2.4. This is the only class registered via object registration.

2.3 Skeletal Hand Model for the Avatar VR Haptic Glove

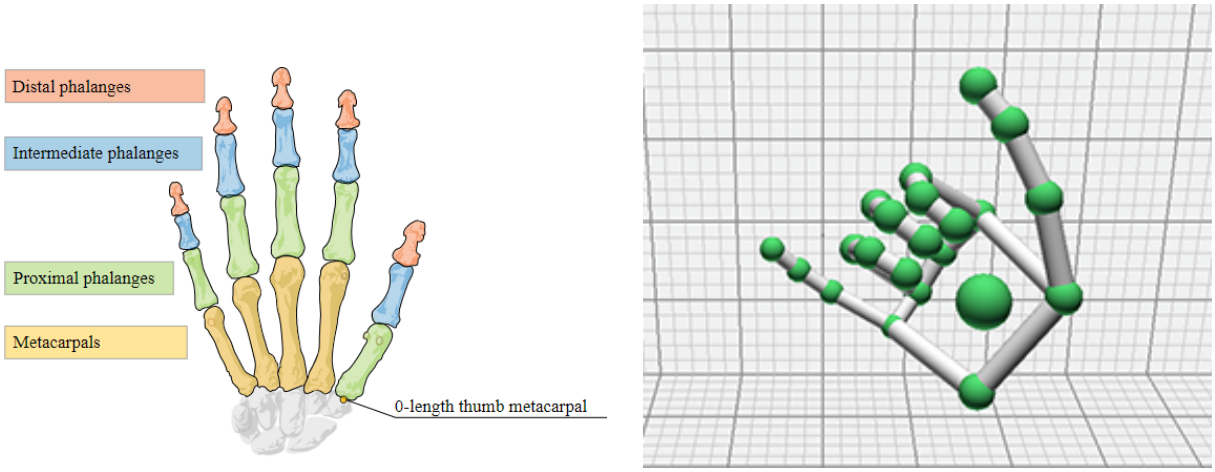
2.3.1 Abstraction of the Human Hand Skeleton

The human hand can be roughly divided into the parts shown in figure 2.3a, i.e. the *metacarpals*, *proximal phalanges*, *intermedial phalanges*, and *distal phalanges*. A joint connecting a metacarpal to a proximal phalanx is called *metacarpophalangeal joint*, and followed by a *proximal interphalangeal joint* and a *distal interphalangeal joint*.

Even though the carpals (grey in figure 2.3a) are physiologically quite relevant for hand movement, they stay relatively fixed compared to the other bone sets, and can thus be omitted in our simplified model. In anataomical nomenclature, the thumb is composed of proximal phalanx and distal phalanx only and follows a metacarpal. However, this model assumes a missing metacarpal and existing intermedial phalanx instead which will be modelled by a 0-length metacarpal for uniformity reasons.

The Leap Motion API version 2.0[lea] uses the abstraction described above and adds

Figure 2.2: Class diagram of `vr_ctrl_panel`, only most relevant elements shown



(a) General bone structure of the human hand

(b) Screenshot of an example hand representation in the Leap Motion API version 2.0, cropped

Figure 2.3: A model of the human hand; from [lea]

- an "end" joint per finger (at the end of the distal phalanx)
- a joint diagonally across the palm from the metacarpophalangeal joint of the index
- a joint in the middle of the palm

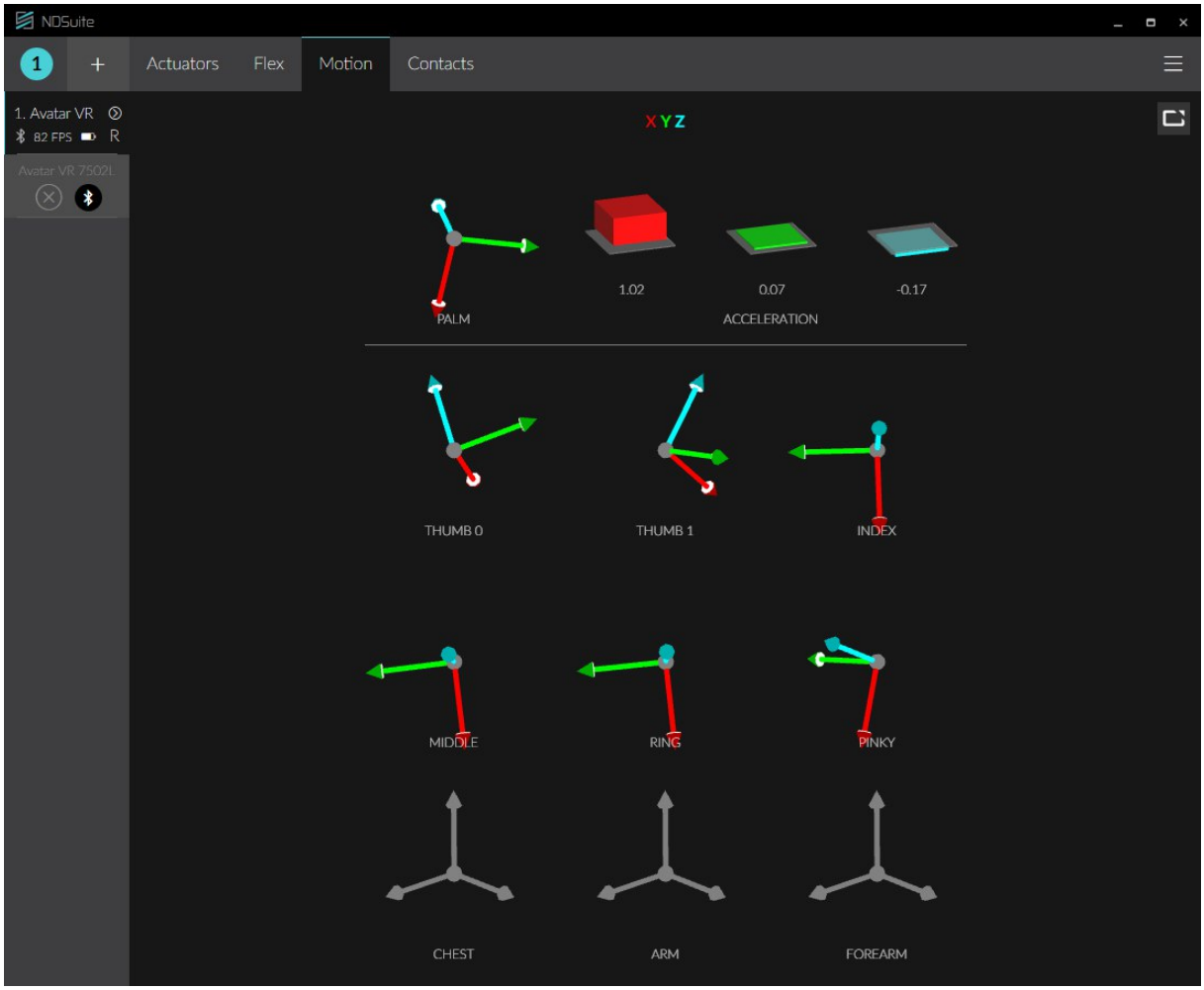
The most common representation includes cylinders for the bones and spheres for the joints. It is shown in figure 2.3b.

2.3.2 Technology and Function of the Avatar VR

The Avatar VR is equipped with three kinds of sensors:

- An *intertial measurement unit (IMU)* is located on the intermedial phalanx of each finger to measure its 3D rotation. The thumb is even equipped with two IMUs (one per phalanx) and the palm with an IMU that can measure both 3D orientation and 3D rotation. The "Motion" tab of ND Suite shown in figure 2.4a depicts the resulting orientations as orthonormal bases.
- At the locations marked in blue in figure 2.4b, the fabric is made of an electrically conductive material. These parts are used as contact sensors (short: contacts) to determine which of the marked locations are joined.
- The thumb also has a flex sensor, that will not be relevant for this thesis.

Furthermore, there are actuators at the locations marked in blue in figure 2.4c. These can be used for haptic feedback in a way that "[. . .] the brain perceives it as 'Real Touch' input", according to the producer.



(a) "Motion" tab of ND Suite with orientations in an (optimistic) example hand pose

(b) Positions of contact sensors

(c) Positions of actuators

Figure 2.4: Sensors and actuators of the Avatar VR;
screenshots of ND Suite (b and c cropped)

2.3.3 Using Data From the Avatar VR to Visualize the User's Hand

The same model used by the Leap Motion API version 2.0 will also be used here. Leap captures absolute joint positions and optimizes them for visualization. In contrast, my approach for the Avatar VR is to use a fixed resting state geometry of the user's hand (bone lengths and resting state joint positions). At the time of a `draw()` command, the geometry is adjusted according to the data given by the glove and the Vive tracker.

The joint position data is managed by the following struct (only most important parts included):

```
struct joint_positions {
        // positions of hand joints in model space
        // structure: hand_part<phalanx<position>>
        vector<vector<vec3>> positions;
        // positions linearized in hand_part major format
        // set by make_array()
        vector<vec3> linearized;
        // correspondence of indices in linearized
        // to double indices in positions
        map<int, pair<int, int>> lin_to_anat;

        // rotate complete part
        void rotate(int part, quat rotation) {...}

        // translate complete part along neg. z-axis
        void translate_neg_z(int part, float z) {...}

        // translate all positions
        // used to move hand from construction origin
        // to model view location
        void translate(vec3 translation) {...}

        // scale all positions
        // used to realize hand size at construction origin
        void scale(float scale) {...}

        // generate linearized from positions
        vector<vec3> make_array() {...}
};
```

First, the palm joints' resting positions are rotated according to the orientation given by the Vive tracker. The construction of each finger begins at the end joint of the distal phalanx which is translated along the negative z-axis by the hard-coded length of the distal phalanx and rotated by the respective quaternion (see below). The other phalanges are constructed in the same manner, before the whole finger is translated to the respective metacarpophalangeal joint. Finally, the whole hand is scaled to model view space

and translated to the model view position of the Vive tracker.

Because the Avatar VR only returns one quaternion per finger (except for the thumb), I had to think of a way to distribute the orientation along all three phalanges: First, the Euler angles are calculated from the quaternion[?]

$$\begin{aligned} \alpha &= \arctan\frac{2(q_0q_1 + q_2q_3)}{1 - 2(q_1^2 + q_2^2)} \\ \beta &= \arcsin(2(q_0q_2 - q_3q_1)) \\ \gamma &= \arctan\frac{2(q_0q_3 + q_1q_2)}{1 - 2(q_2^2 + q_3^2)} \end{aligned}$$

where α is the roll angle, β the pitch angle and γ the yaw angle, and the quaternion can be written as (q_0, q_1, q_2, q_3). For implementation, one has to use the `atan2` function, because `arctan` only return values between $-\frac{\pi}{2}$ and $\frac{\pi}{2}$.

The `NDAPI` quaternions live in a space where the resting hand lies on the xz-plane and the fingers point along the positive z-axis. However, `vr_ctrl_panel` is oriented with the negative z-axis as "front" direction, so q_1 and q_2 need to be negated before use. Then roll corresponds to bending the finger, pitch to a left-right-motion and yaw to a motion humans can hardly perform with their fingers.

Since the interphalangeal jionts act as revolute joints, only a roll component can be applied to them. As shown in the code below, the roll angle is distributed according to three floats (`rot_split`). After some experimenting, $(.5, .5, .25)$ is an option for these numbers that gives a good approximation of most actual hand poses. It corresponds to phalanx rotation during grabbing. Yaw and pitch are completely executed in the metacarpophalangeal joint.

```
vec3 x(1, 0, 0), y(0, 1, 0), z(0, 0, 1);
recursive_rotations[finger][PROXIMAL] = palm_rotation
        * quat(z, yaw) * quat(y, pitch) * quat(x, rot_split.x() * roll);
recursive_rotations[finger][INTERMED] = quat(x, rot_split.y() * roll);
recursive_rotations[finger][DISTAL] = quat(x, min(1.4f, rot_split.z() * roll));
```

2.4 calibration

Glossary

distal interphalangeal joint joint connecting an intermedial phalanx to a distal phalanx. 2

distal phalanx finger bone farthest from the palm of the human hand, shown in figure 2.3a. 2, 4, 6

intermedial phalanx finger bone of the human hand between proximal phalanx and distal phalanx, shown in figure 2.3a. 2, 4

metacarpal set of bones in the palm of the human hand, shown in figure 2.3a. 2, 4

metacarpophalangeal joint joint connecting a metacarpal to a proximal phalanx. 2

proximal interphalangeal joint joint connecting a proximal phalanx to a intermedial phalanx. 2

proximal phalanx finger bone closest to the palm of the human hand, shown in figure 2.3a. 2, 4, 6

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[PGP+10] Philipp Pohlenz, Alexander GrÃ¶be, Andreas Petersik, Norman [von Sternberg], Bernhard Pflesser, Andreas Pommert, Karl-Heinz HÃ¶hne, Ulf Tiede, Ingo Springer, and Max Heiland. Virtual dental surgery as a new educational tool in dental school. *Journal of Cranio-Maxillofacial Surgery*, 38(8):560 – 564, 2010.

Acknowledgments

I’d like to thank...

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