Prototyping and Evaluating Sensory Substitution Devices by Spatial Immersion in Virtual Environments

gipsa-lab

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Sensory Substitution Devices (SSD)

Sensory substitution consists in replacing an impaired sensory channel by another, functional, one.
Most SSD are used to compensate visual impairments by the auditory or tactile senses.

The user positions the sensor

Environment → Sensor → Transcoder → Actuator
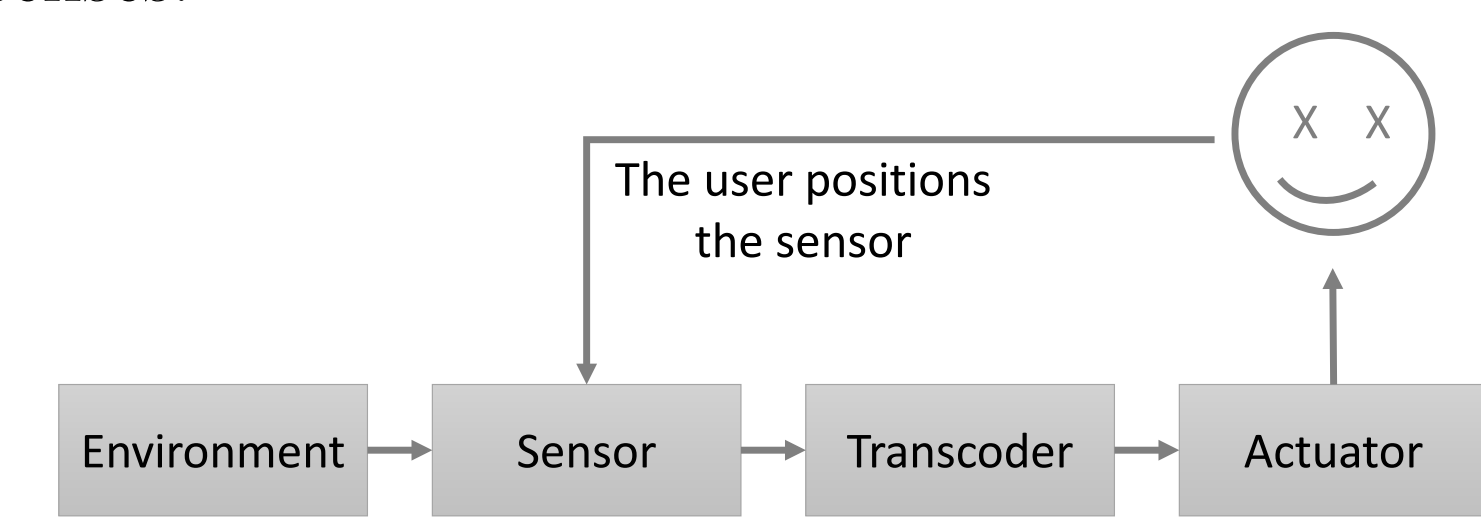
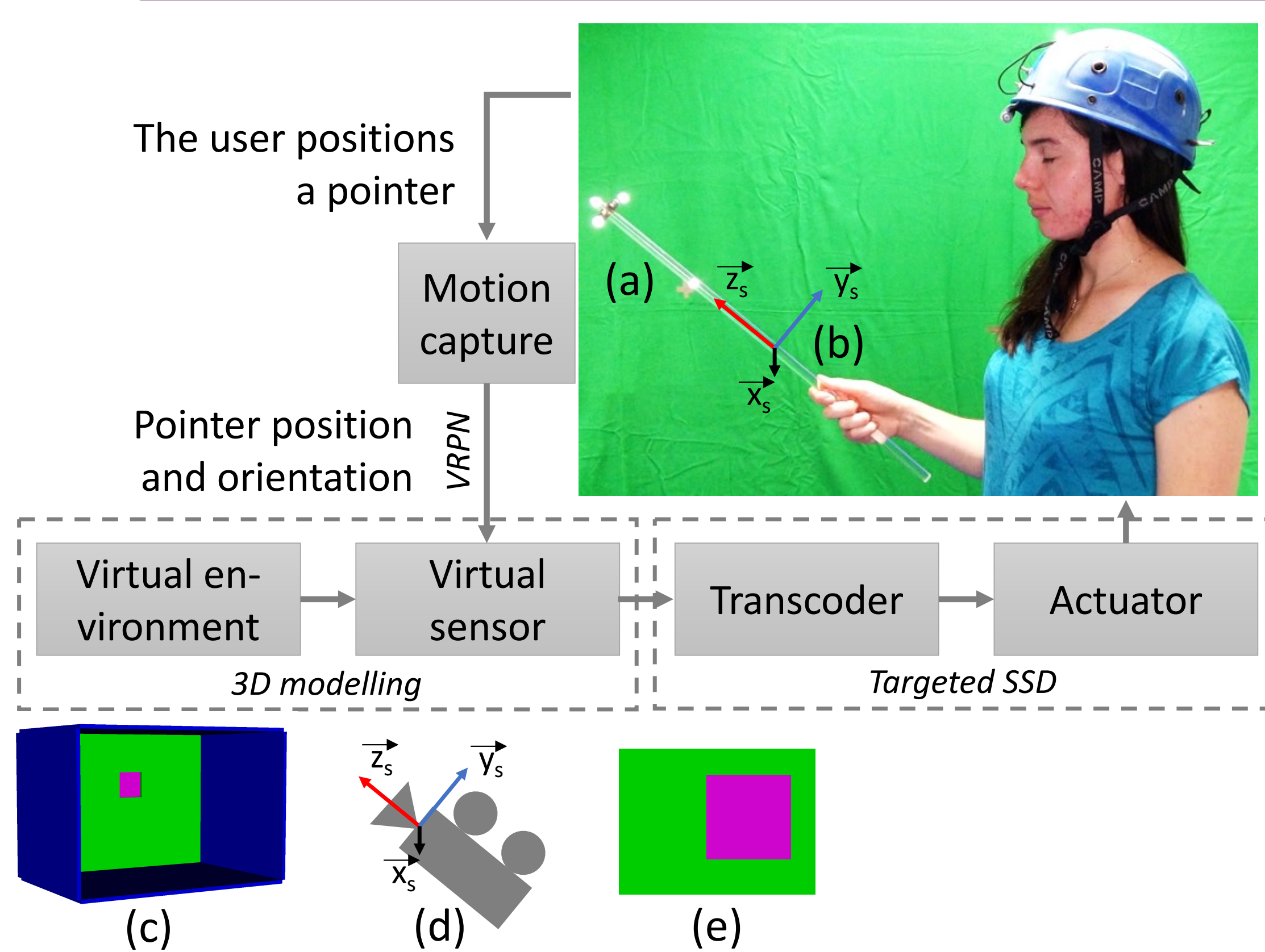Electronic sensory substitution device principle

Problematic: prototyping and evaluating SSD

Prototyping and Evaluating of an SSD in the real world:

- can only be done after a complete prototype has been built, which may be long and tedious,
- requires either a complex natural scene which makes difficult the adjustment and evaluation of the transcoding laws or a simplified real laboratory scene specifically constructed, long to set up and hard to replicate.

To get close to real-life sensory and motor experience we constructed an experimental set-up which immerses the whole user in the virtual 3D environment that he perceives through a SSD.

Designed experimental set-up principle

The user positions a pointer

Motion capture

Pointer position and orientation

VRPN

Virtual environment → Virtual sensor — 3D modelling

Transcoder → Actuator — Targeted SSD

(a) (b) (c) (d) (e)

- **Modeling the virtual environment**
  We used the OpenSceneGraph 3D modelling library to describe the environment. **(c)** a virtual environment example: wall pierced by a square window.

- **Virtual environment capture**
  The virtual environment is captured by a virtual sensor, an OpenSceneGraph camera **(d)**.

- **Matching real and virtual**
  The user manipulates the virtual sensor from the real world. VICON motion capture system extracts a real object position and orientation **(a)** represented by the referential **(b)** replicated on the virtual sensor **(d)**.

- **Interfacing with the transcoder**
  We extracted information from the virtual sensor compatible with the targeted SSD transcoder. **(e)** viewpoint of the virtual sensor.

Experiment 1: detecting an open window on a virtual wall
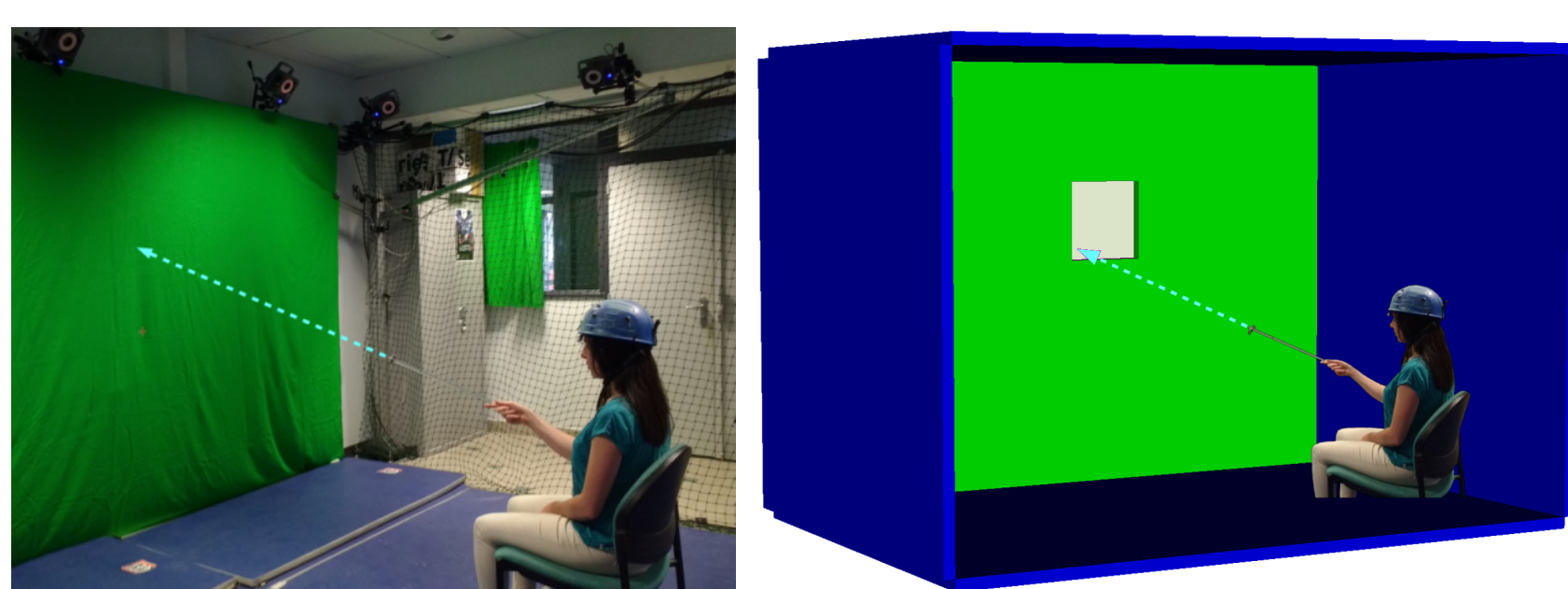
Task: locate an open window on a wall:

- with a stick held by the hand or a headset,
- the window could be in the four quadrants and two different sizes: large or small,
- the sound pitch was an octave of difference whether the pointer was directed to the open window or not,
- 7 participants, 64 trials for each.

Performance analysis with a linear model with mixed effects (pt: pointer, siz: size, pos: position, par: participant) which simplified as:

$$Y_{pt,siz,pos,par} = \mu + \beta_{siz} + \gamma_{pos} + \tau_{par} + \epsilon$$

⇒ big windows are faster to locate than small ones and the pointing devices can be considered as equivalent in this task.

Experiment 2: walking through an open door separating virtual rooms

Pointer
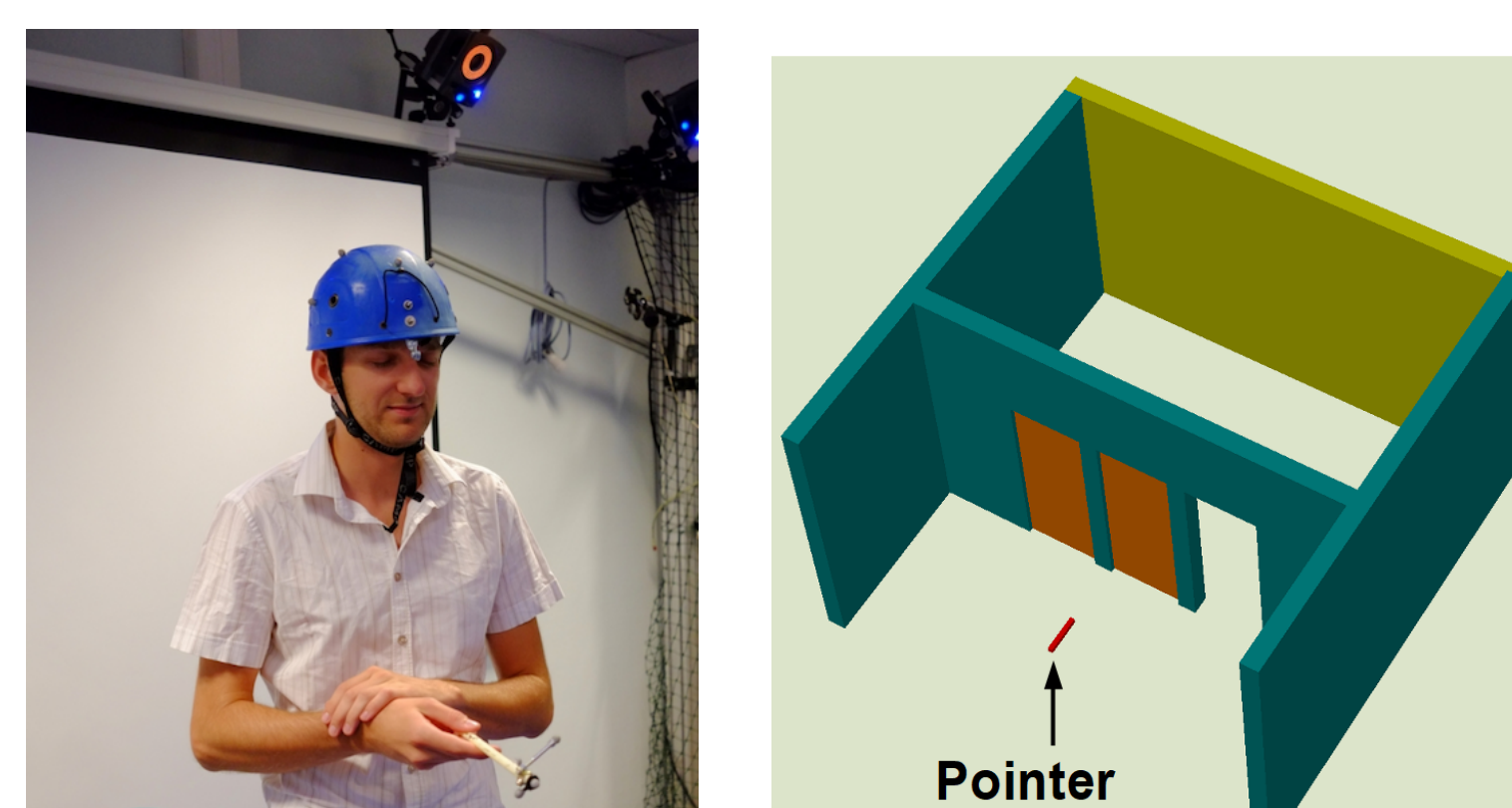
Task: Starting from the front room, locate the open door and walk through it into the back room:

- one of the three doors was randomly open,
- the sound pitch was a monotonous function of depth, i.e., distance from the end of the pointing device to the pointed surface,
- the pointing device was a stick held by the hand or a headset,
- 5 participants, 36 trials for each.

Performance analysis was conducted with a linear model with mixed effects which simplified as:

$$Y_{pt,pos,par} = \mu + \beta_{pos} + \tau_{par} + \epsilon$$

⇒ the door crossing delay only depends on the door position and the participant, not on the pointer.

Conclusions

- The experimental set-up has shown efficient for evaluating SSDs and for designing novel ones.
- A virtual 3D space offers worthy means of testing SSD by conducting various tasks in various environments.
- Both pointing devices lead to equivalent performances. Headset advantage: hands free but uncomfortable head scanning movements.

Using an eye-tracker as a pointing device: blind people with residual eye motricity could point to obstacles or targets without scanning with head movements, and keeps hands free.

VRPN — Motion capture

(a) Glasses coordinates in the motion capture referential

SMI iViewETG

(b) Gaze coordinates in the glasses referential

SMI iViewETG 3D-6D

VRPN

(c) Gaze vector in the motion capture referential

Virtual environment → Virtual sensor → Transcoder → Actuator

Experimental set-up with eye-tracker

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