(Pre-) Processing eye tracking data

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Tea Time presentation WiSe23/24
Do, 09.11.2023

Processing eye tracking (ET) data

1. Calibration & validation of ET system
2. Collider Selection for hits
3. Validating the recorded data
4. Blink detection / interpolation of subsequent hits
5. Smoothing the data
6. Removing inconsistencies in subsequent hits

This version is less accurate, but seems to be performing well enough when comparing it with wd-village eye-tracking data

Calibration/Validation & Error-Check

- 5-point calibration
  - Vive pro eye calibration (out-of-the-box solution, SRanipal)
- 5-point validation
  - Custom-made by N. Maleki (2021)
  - Design & mechanism aim to resemble Vive Pro Eye calibration
  - Different order, movement speed etc. opposed to calibration
- 1-point error check
  - Additional feature in SpaRe: 1-point validation allowing for < 1° angular error
  - Serves as a short check whether the eye tracker is still recording correctly
  - ➢ Useful time-saver for extensive recordings with not too much movement

```
private const float ErrorThreshold = 1.0f;

// give feedback whether the error was too large or not
if (CalculateValidationError(anglesX) > ErrorThreshold ||
    CalculateValidationError(anglesY) > ErrorThreshold ||
    CalculateValidationError(anglesZ) > ErrorThreshold ||
    _eyeValidationData.EyeValidationError == Vector3.zero)
```

→ **Complete calibration and validation** of the eye tracker **every 5 to 10 minutes**!

→ In cases where this is not possible or even counterproductive to the goal of the experiment, a **1-point error check can be used to indicate** whether re -calibration/-validation is required.

Selecting relevant colliders SpaRe

- In general, we can assume that participants looked at the *closest* (distance in unity units) object that was hit by their gaze.
- Exceptions to this rule depend on the exact research question at hand and the dynamics of the (virtual) environment. For example, objects that are visible behind transparent or invisible objects might be relevant to navigation.

➢ Therefore, in Westbrook we replace hit head colliders (invisible) and transparent objects (i.e., scaffolding, fences/barbwire, small posts). Specifically, only if the gaze hit an object that was visible right behind the invisible/transparent one.

When determining your approach, **focus on your research question** to determine what objects are most relevant to you. Invisible objects can usually be ignored, dealing with transparent, small, or thin objects can be more tricky. We recommend to determine your approach well in advance!

Selecting relevant colliders wd-village

- As in SpaRe, we assume that participants looked at the closest collider hit.
- In this study, we ordered colliders according to the distance and kept the closest. (This is due to GazeRayAll)
- For our purposes, we had collides fitted as best as possible to all objects and only corrected for a small number:
  - We took out the invisible object ‘BodyCube’ (related the the NavMesh)
  - If the first hit was on a body and the second hit on the head of the same avatar, we took the head collider instead (the colliders were sometimes overlapping).

When determining your approach, **focus on your research question** to determine what objects are most relevant to you. Invisible objects can usually be ignored, dealing with transparent, small, or thin objects can be more tricky. We recommend to determine your approach well in advance!

Using SRanipal we have three different parameters

Pupil diameter:

- when glasses not worn, or when eyes closed: **-1**
- when eyes open: between **0 and 5** (guessed; it was always between 2 and 4.5)

Validata Bitmask

- **8** when glasses not worn
- **8** when eyes closed
- **>8** when eye(s) open

Eye Openness (When the glasses are not worn, the eye openness is falsely logged as “1” !)

- **1** when glasses not worn
- Ca. **0** or close to 0) when eyes closed
- Ca. **>0.05** when eyes open, often 1

➔ A **valid ET sample** contains a pupil diameter of 0-5, a bitmask of >8, and an eye openness of >.05

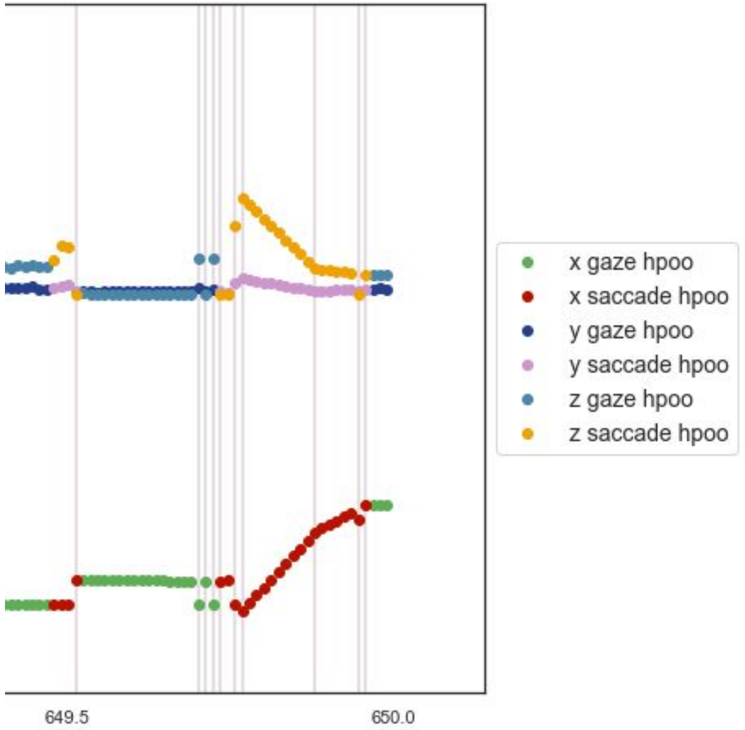
➔ According to our tests, these **parameters should not be used in isolation**! Especially eye openness can lead to the inclusion of incorrect samples as it cannot distinguish between open eyes and no eyes being detected!

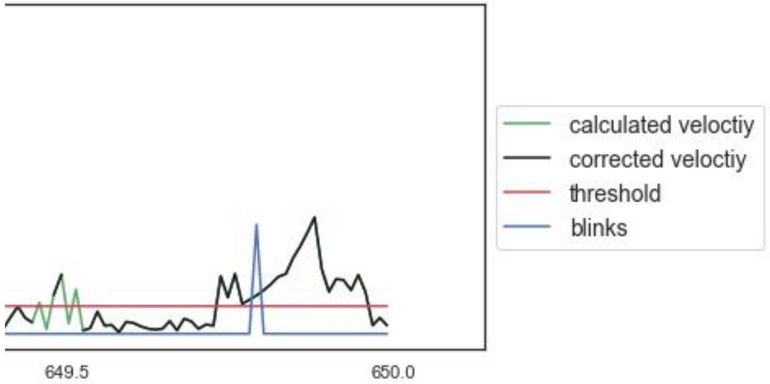
Using TobiiXR we have:

Using TobiiXR, we have a lot less information available:

- **IsValid**: bool, indicates the validity of the GazeRay
- **IsLeftEyeBlinking**: bool
- **IsRightEyeBlinking**: bool

→ We define invalid samples when the GazeRay was **invalid**, **both eyes** were **blinking** and/or the eye-tracking **origin changed rapidly**, converging towards (0,0,0) which was far away from the actual position.





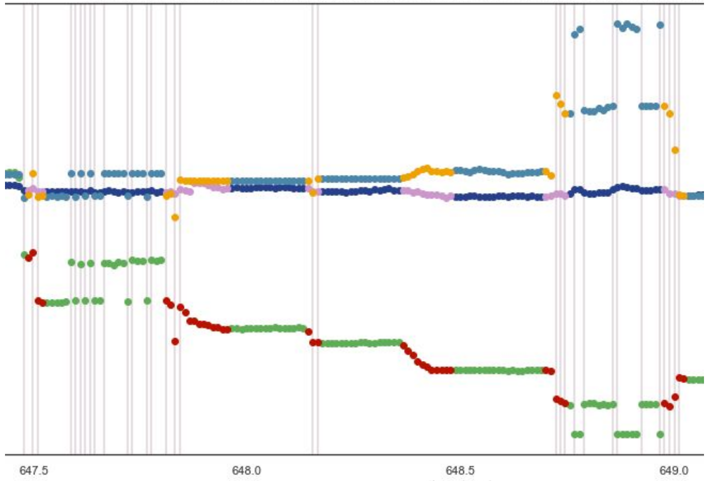
Blinking correction + Interpolation

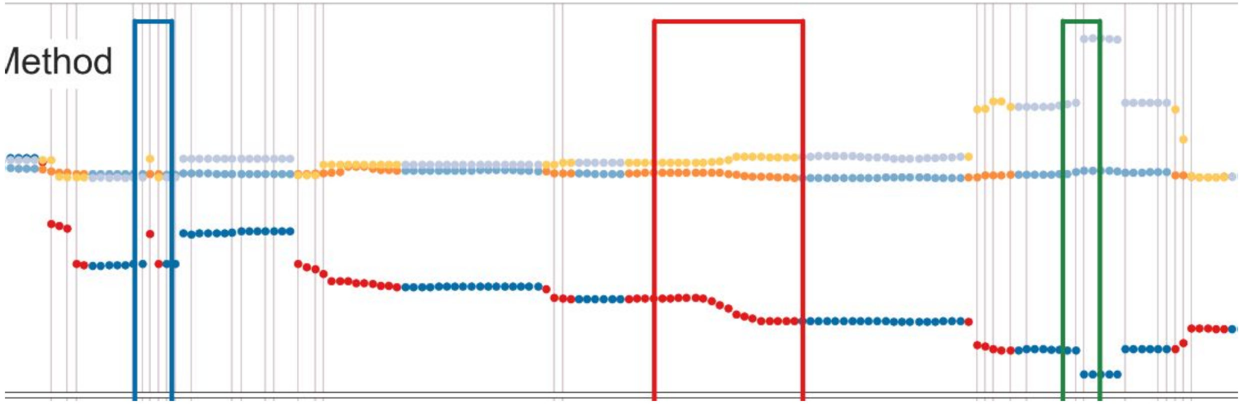
- Blink correction was done according to Dar et al. (2021): https://link.springer.com/article/10.3758/s13428-020-01428-x
- Detect **invalid samples** in the data
- Blink detection:
  - **min blink duration**: 20 ms
  - If an 'invalid interval' is bigger or equal than min_blink_duration, we replace values with nans samples before and after the invalid interval.
  - The time to be replaced will be up to **23 ms** (for 90 Hz, it is usually two samples).
- Interpolation:
  - Collider names are only interpolated if there is one sample between them, otherwise we keep nans.
  - **Linear interpolation** (both directions) for all other variables.
  - If it is **bigger than 250 ms**, set all variables in the intervals to nan instead.

We preprocess the data, ensuring that there are no invalid samples considered when determining gazes and saccades.

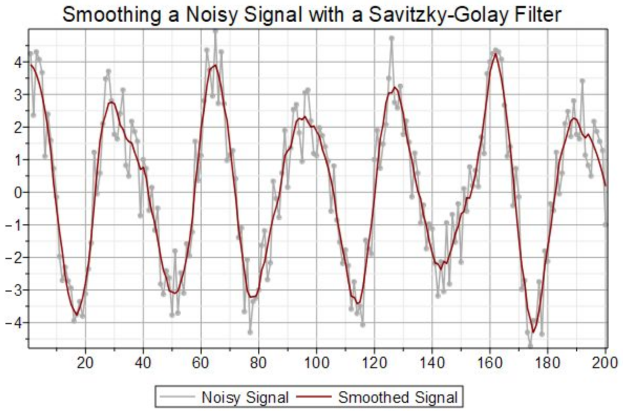
ET Algorithm: Applying filters

- 5-point median filter



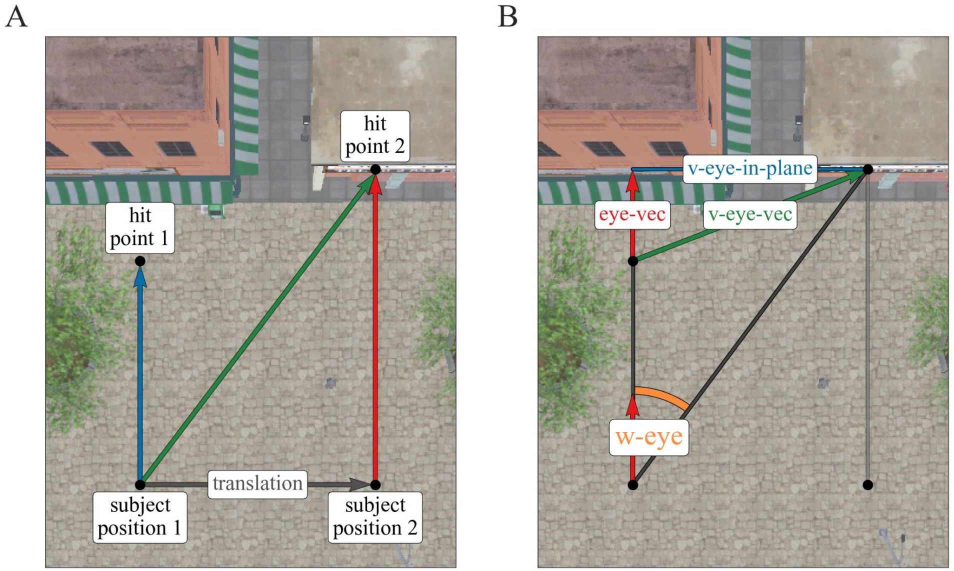


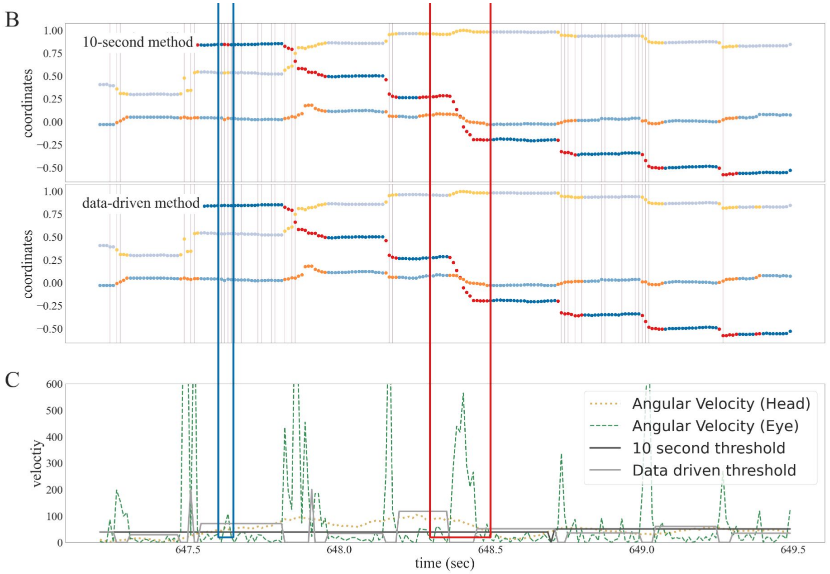
- Savitzky–Golay filter

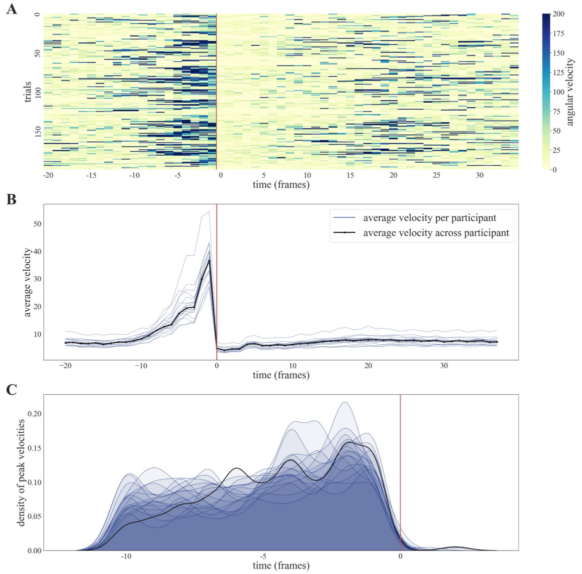


ET Algorithm: Defining Gazes

→ talk to us if you have questions!







ET Algorithm: Defining the hits

→ Using a velocity-based ET algorithm, it could result in different colliders being 'hit' during the same gaze event.

→ We define the most often hit collider (excluding nans) during a gaze event as the looked-at collider.

hon	hon_all	xhop	yhop	zhop
NPC-4623	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
BasketbalcourtLines	BasketbalcourtLines	615.5599975585938	0.3289999961853027	640.239990234375
NPC-4623	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
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	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
Park_Center	Park_Center	617.6199951171875	0.1099998950958252	627.283203125
NPC-4623	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
Park_Center	Park_Center	617.6199951171875	0.1099998950958252	627.283203125
NPC-4623	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
	NPC-4623	615.9409790039062	0.3029999732971191	624.43701171875
Terrain	Terrain	0.0	-0.0009999275207519	0.0

events	length	distance	avg_dist	names
-1.0	0.3780000000000427	67.63771173808793	67.64094369876297	Bush_qilgP2_6x6x4_...
2.0	0.3319999999999936	40.59775712481537	40.59460978705646	NPC-4623
	0.3319999999999936	40.59711478336789	40.59460978705646	NPC-4623
	0.3319999999999936	40.59711478336789	40.59460978705646	NPC-4623
	0.3319999999999936	40.59720637939929	40.59460978705646	NPC-4623
	0.3319999999999936	40.59682347422389	40.59460978705646	NPC-4623
	0.3319999999999936	40.59682347422389	40.59460978705646	NPC-4623
	0.3319999999999936	40.5968033855791	40.59460978705646	NPC-4623
	0.3319999999999936	40.5950737159462	40.59460978705646	NPC-4623
	0.3319999999999936	40.5950737159462	40.59460978705646	NPC-4623
	0.3319999999999936	40.5950737159462	40.59460978705646	NPC-4623
	0.3319999999999936	40.59550087357052	40.59460978705646	NPC-4623
	0.3319999999999936	40.59550087357052	40.59460978705646	NPC-4623
	0.3319999999999936	40.59550087357052	40.59460978705646	NPC-4623
	0.3319999999999936	40.59451832745607	40.59460978705646	NPC-4623
	0.3319999999999936	40.59381796687767	40.59460978705646	NPC-4623
	0.3319999999999936	40.59334879942494	40.59460978705646	NPC-4623
	0.3319999999999936	40.59334879942494	40.59460978705646	NPC-4623
	0.3319999999999936	40.59334879942494	40.59460978705646	NPC-4623
	0.3319999999999936	40.59338961450069	40.59460978705646	NPC-4623
	0.3319999999999936	40.59360294874702	40.59460978705646	NPC-4623

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Defining Events for EEG

- Global_Landmark
- TaskBuilding_Public
- TaskBuilding_Residential
- Other_Buildings
- Background

Timeline

1. Defining the closest hit for each timestamp.
2. Selecting blinks: replace invalid samples with nans.
3. Linear interpolation: interpolate everything other than the collider names.
4. Replace everything bigger than 250 ms with nans.
5. The ET algorithm:
    a. Applying filters
    b. Defining gazes/saccades
    c. Selecting the hit collider
6. Profit (data analysis)

Adding additional Slides

If you have ideas, questions or old slides, feel free to add these behind this slide.

Please do not erase any content from the previous slides.

Thanks,
Debbie and Vincent

Jasmin's Slides 1

Old version with threshold

Preparation

- Unflattening JSONs
  - keep original data structure-
- Rename all colliders (1. & 2. hits) based on list → collider name & collider bounds update
- Replace body hits (1. hit = body & 2. hit = not body)
- Rename graffiti hits to building name (1. & 2. hits) →collider name & collider bounds update
- Rename everything that is not a building to NH
- Rename 1st hits if NH and 2nd is not
- identify samples with bad quality & rename them to noData & NaN → combined gaze validity bitmask is not 3
- exclude unnecessary variables

Gaze algorithm

- condense date into clusters
- Check - whether to exclude participants
- Join sessions
- Interpolation (threshold)
- Gaze detection (threshold)
- Graphs

New Proposal - how similar is it to the current EEG SpaRe?

Preparation

- Unflattening JSONs
  - keep original data structure-
- Rename all colliders (1. & 2. hits) based on list
  → collider name & collider bounds update
- Rename graffiti hits to building name (1. & 2. hits)
  → collider name & collider bounds update, mark renamed rows
- **Create new collider columns**
  → collider name, hit point, collider center
  - Use 1. hit & verify nearest distance - eye position
  - Replace body hits of 1st hit (1. hit = body & 2. hit = not body) → mark rows
- **Duplicate new (orange) collider column**
  - Rename everything that is not a building to NH
  - Rename 1st hits if NH and 2nd is not
- exclude (unnecessary) **empty** variables

Gaze algorithm

- Cleaning:
  identify samples with bad quality & rename them to noData & NaN
  → combined gaze validity bitmask ≠ 3
  → eye openness < ?
- Check - whether to exclude participants
- Interpolation (linear)
- Smoothing
- Gaze detection REMoDNaV DN Implementation
- Check orange colliders
- Check NH colliders
- Join sessions
- Graphs

Jasmin's Slides 2

- What processing aspects are general processing, project specific (related to the used hardware, VR design), or topic/analysis specific?
  - Use general processing steps to develop "core processing procedure"
  - Project specific things should be consistent within the same VR environment
  - Topic/analysis specific will differ for every research question/analysis

Topic/Analysis specific

- Rename everything that is not a building to NH
- Rename 1st hits if NH and 2nd is not
- Unflattening JSONs - keep original data structure-
- exclude (unnecessary) **empty** variables
- Join sessions
- Graphs

Project Specific → VR HDM & programming

- Rename all colliders (1. & 2. hits) based on list → collider name & collider bounds
- Use 1. hit & verify nearest distance
- Rename graffiti hits to building name (1. & 2. hits) → collider name & collider bounds update, mark renamed rows
- Replace body hits of 1st hit (1. hit = body & 2. hit = not body) → mark rows
- See-through colliders?
- Cleaning: identify samples with bad quality & rename them to noData & NaN → combined gaze validity bitmask ≠ 3 & eye openness
- Check - whether to exclude participants

General Processing

- *Project specific cleaning consistent for used hardware?*
- Interpolation (linear)
- Smoothing
- Gaze detection REMoDNaV DN Implementation
- Check colliders → consistent within 1 gaze

Jasmin's Slides 3

➔ Important differences between Jasmin, Tracy and Debora/Vincent

Rename all colliders (1. & 2. hits) based on list
→ collider name & collider bounds update

Use 1. hit & **verify nearest distance**
- ➔ Debbie/Vincent & Tracy use body tracker position to calculate distance - but that is how the Raycast is calculated in VR
- ➔ Raycast in Recording Script uses:
  - ◆ eyePositionCombinedWorld,
  - ◆ eyeDirectionCombinedWorld
- ➔ eyePositionCombinedWorld = verboseData.combined.eye_data.gaze_origin_mm / 1000 + hmdTransform.position;

See-through colliders?

Cleaning:

identify samples with bad quality & rename them to noData & NaN

- ➔ Jasmin & Tracy: combined gaze validity bitmask ≠ 3
- ➔ Vincent & Debbie: combined bitmask & eye openness

Interpolation
- ➔ Jasmin - threshold
- ➔ Tracy - none
- ➔ Debbie & Vincent - linear & threshold

Timestamp used in algorithm: LSL time or
End-timestamp (and to exclude duplicates) → Tracy

Problem - before fixing bug in new version end-timestamp is least reliable. Double timestamps but different data in rows
Better - use start timestamp - and kick out few doublications

Check colliders → consistent within 1 gaze
- ➔ Renaming of colliders before the algorithm- especially NH might matter at this step

unsure, but probably the same details

Unflattening JSONs
- keep original data structure-

Replace body hits of 1st hit (1. hit = body & 2. hit = not body) → mark rows

Rename graffiti hits to building name (1. & 2. hits) → collider name & collider bounds update, mark renamed rows

Rename 1st hits if NH and 2nd is not

Rename everything that is not a building to NH

Check - whether to exclude participants

exclude (unnecessary) **empty** variables

Jasmin's Slides 4 - pre-processing pipeline Nov. 23

New Proposal - how similar is it to the current EEG SpaRe?

Preparation

Unflattening JSONs
- keep original data structure-

exclude (unnecessary) **empty** variables

Rename all empty collider hit names to "noHit"

Rename all colliders (1. & 2. hits) based on list
→ collider name & collider bounds update

Rename graffiti hits to building name (1. & 2. hits)
→ collider name & collider bounds update, mark renamed rows

Create new collider columns: processedCollider

~~Use 1. hit & verify nearest distance - eye position~~

Replace see-through colliders with 2nd hit -
→ use list of 6 colliders by Vincent and Debbie, mark rows

Replace body hits of 1st hit
→ use both 'Body' & 'body' collider names, use rule 1. hit = body & 2. hit = not body → mark rows

Duplicate new (orange) collider column

Rename everything that is not a building to NH

Rename 1st hits if NH and 2nd is not

Gaze algorithm

Cleaning:
identify samples with bad quality & rename them to noData & NaN
→ combined gaze validity bitmask ≠ 3
→ eye openness < ?

Interpolation (linear)

Smoothing

Check - whether to exclude participants

Gaze detection REMoDNaV DN Implementation

Check orange colliders

Check NH colliders

Join sessions

Graphs

Jasmin’s Slides 5 - new adaptation & differences

Gaze algorithm

Cleaning:

Jasmin’s adaptation
a good data sample is if:
- combined eye bitmask == 3
- and ('eyeOpennessLeft' >= 0.05 | eyeOpennessRight' >= 0.05)
- and

Debbies code
a good data sample is if:
- gazeValidityCLR.Combined"] != 8
- and ("eyeOpennessLR.LeftEye" >= 0.05) | "eyeOpennessLR.RightEye"] >= 0.05)
- and ("LeftEye_mm" != -1 | "RightEye_mm" != -1)

Interpolation (linear)
1. Hit on collider issue - if there is not a hit (e.g. sky) - the hit on collider coordinates are NaN, so they get interpolated
2. Blinks - if there are blinks, the data is still being interpolated - does this make sense? Should we not exclude blinks in general?
3. Individual missing/bad data collider names between the same colliders are interpolated

Smoothing

Check - whether to exclude participants

Gaze detection REMoDNaV DN Implementation

Check orange colliders

Check NH colliders

Join sessions

Graphs

Tracy’s Version

From Json to CSV

- json.loads(data)
- pd.json_normalize()
- .apply(pd.Series).add_prefix(“ ”)

Selecting one hit per sample

Calculate the eucledian distance of the 2 hits to the participant. Keep the closest hit unless that hit is classified as background

Drop duplicated rows

If temporal shift is higher that 0.001 seconds (1000Hz) we drop the line.

From collider names to categorical

Collider names are too detailed, we create a dictionary using regular expression patterns to classify them into our categories of interest. All that is not classified in those categories is classified as background.

Remove invalid sections

Flag begging and end of all combined combinedGazeValidityBitmask != 3

Replace values coordinate values with NaNs

5 point median filter

eyePositionCombinedWorld

Debora’s REMoDNaV

We used a 10 second window instead of adaptive threshold

Remove gazes longer than 3.5 Median Standard Deviations

If the gaze length is more than 3 MSD from the entire data set we delete the gaze event.

(Post-) Processing eye tracking data - second session

- after cleaning, extending, creating df-

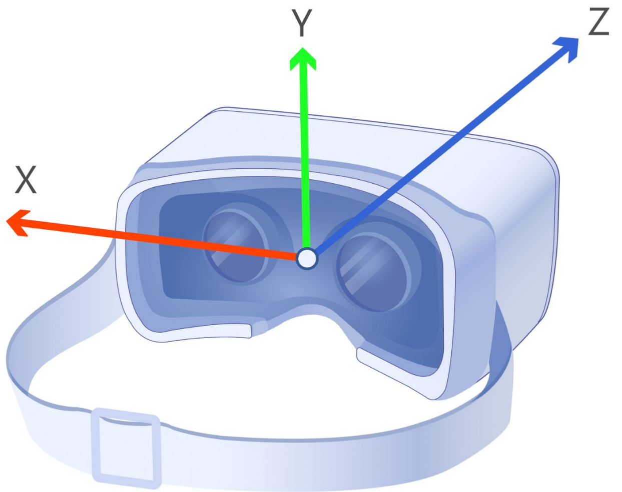
John Madrid, Shadi Derakhshan
Tea Time presentation WiSe23/24
Do, 16.11.2023

What you are given as raw data?

Tobii Pro SDK

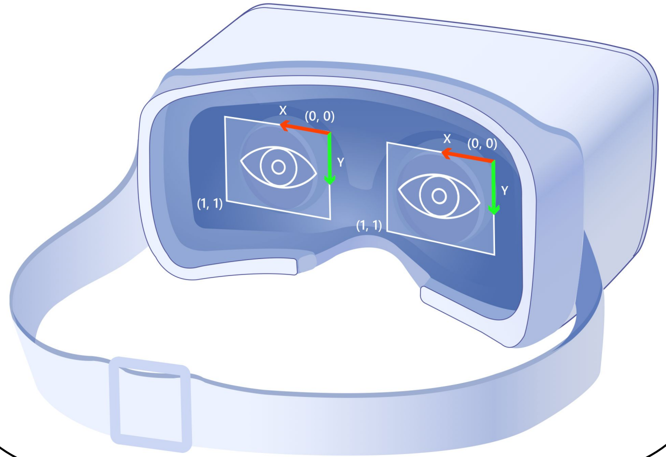
HMD Coordinate system

- ➔ Tobii’s data describe 3D space coordinates
- ➔ it is a millimeter-based system with its origin at a point in between the lenses of the HMD device, at equal distance from each lens' center.
- ➔ **Is this the case for everyone?**



HMD Tracking area

- ➔ A two dimensional "track box", or "HMD Tracking Area", is defined for each eye.
- ➔ The HMD Tracking Area is a normalized 2D coordinate system with it's origin (0, 0) in the top right corner (from the wearer's point of view), and (1, 1) in the lower left corner.
- ➔ **HMD Position:** Ideally, each eye should be positioned in the middle of the tracking area, at coordinates (0.5, 0.5).



What you are given as raw data?

Data

Eye-tracking

Head-tracking

Body-tracking

Other…

Local and Global

Positions (x, y, z)

Directions (x, y, z)

Rotations (x, y, z, w)

…

Use cases

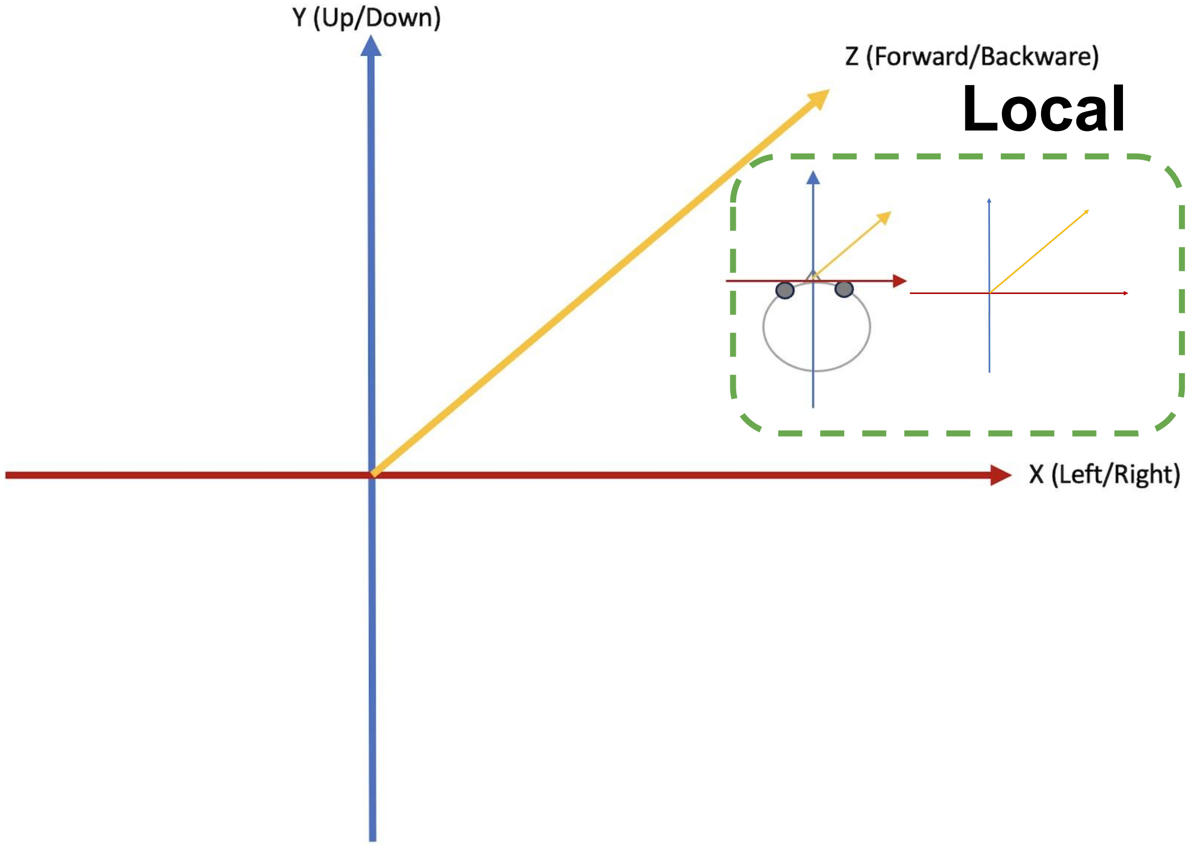
- ➔ Distance: (approaching behaviour)
- ➔ Angles (degrees)
- ➔ Velocity

What you are given as raw data?

Global

vs.

Local

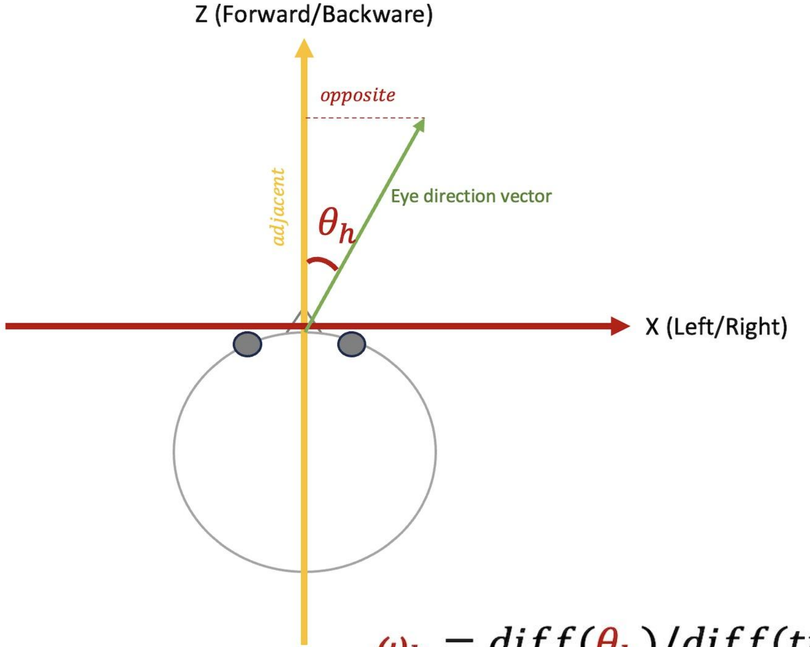


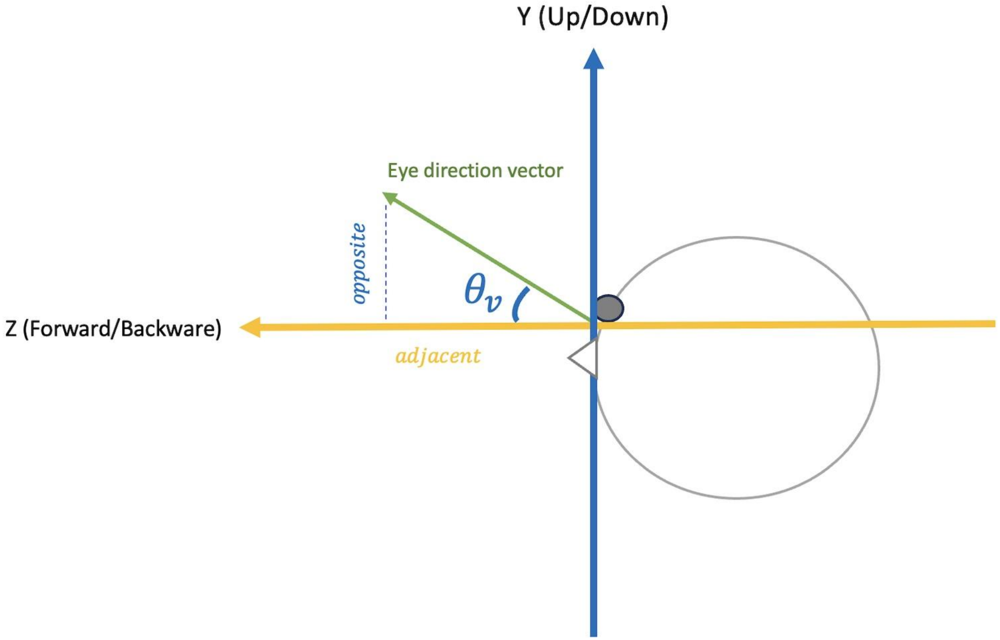
What can you calculate based on that?

- **direction vector ⟹ angles and velocity**

$$\theta_h = tan^{-1}(\frac{opposite}{adjacent})$$

$$\theta_v = tan^{-1}(\frac{opposite}{adjacent})$$

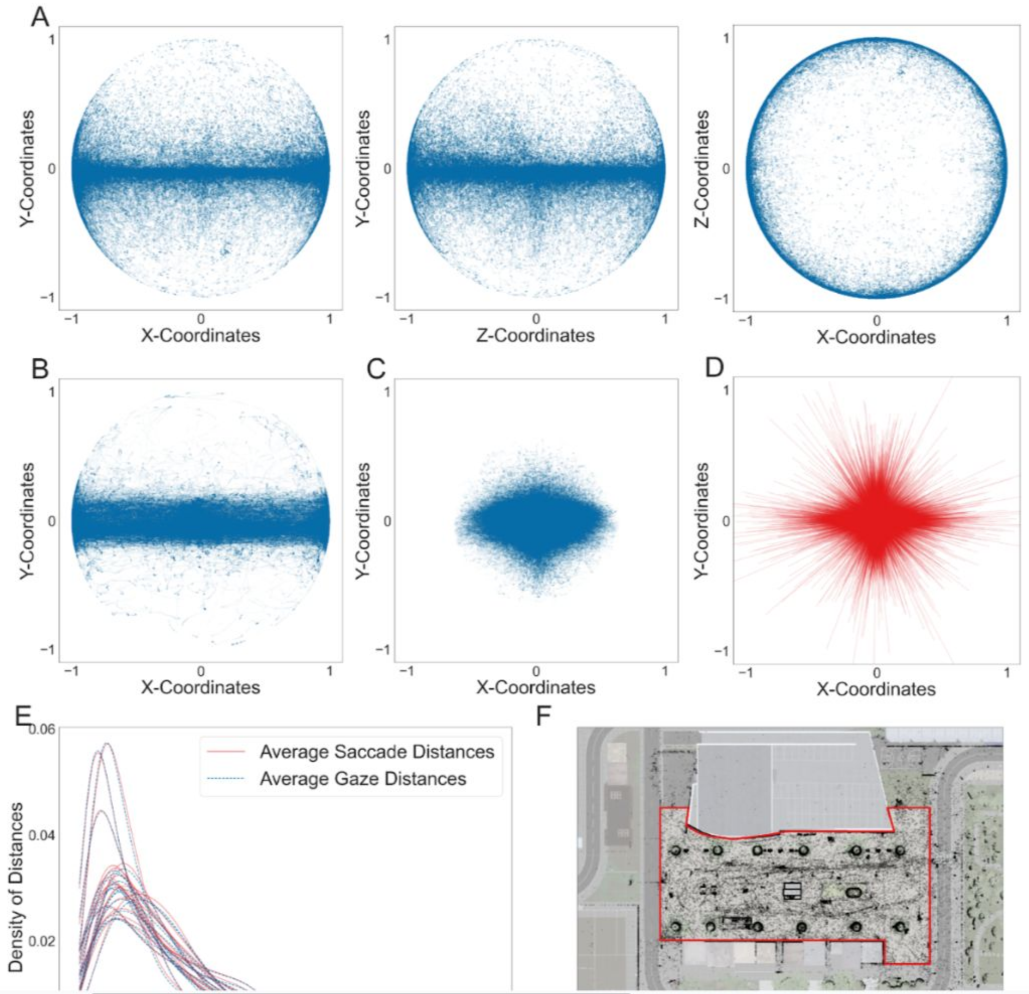




$$\omega_h = diff(\theta_h)/diff(time)$$

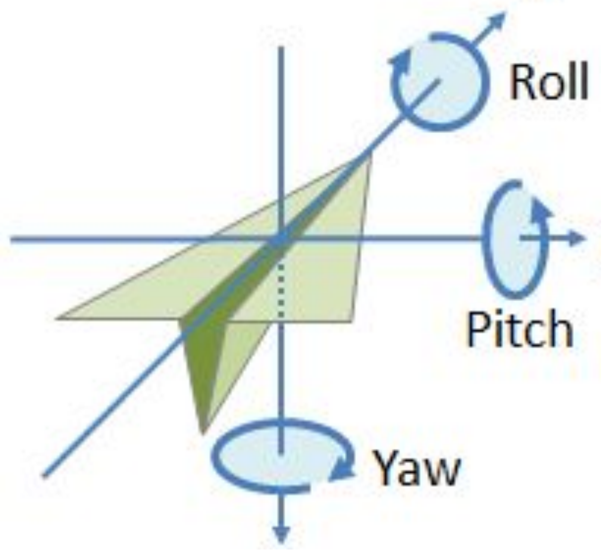
$$\omega_v = diff(\theta_v)/diff(time)$$

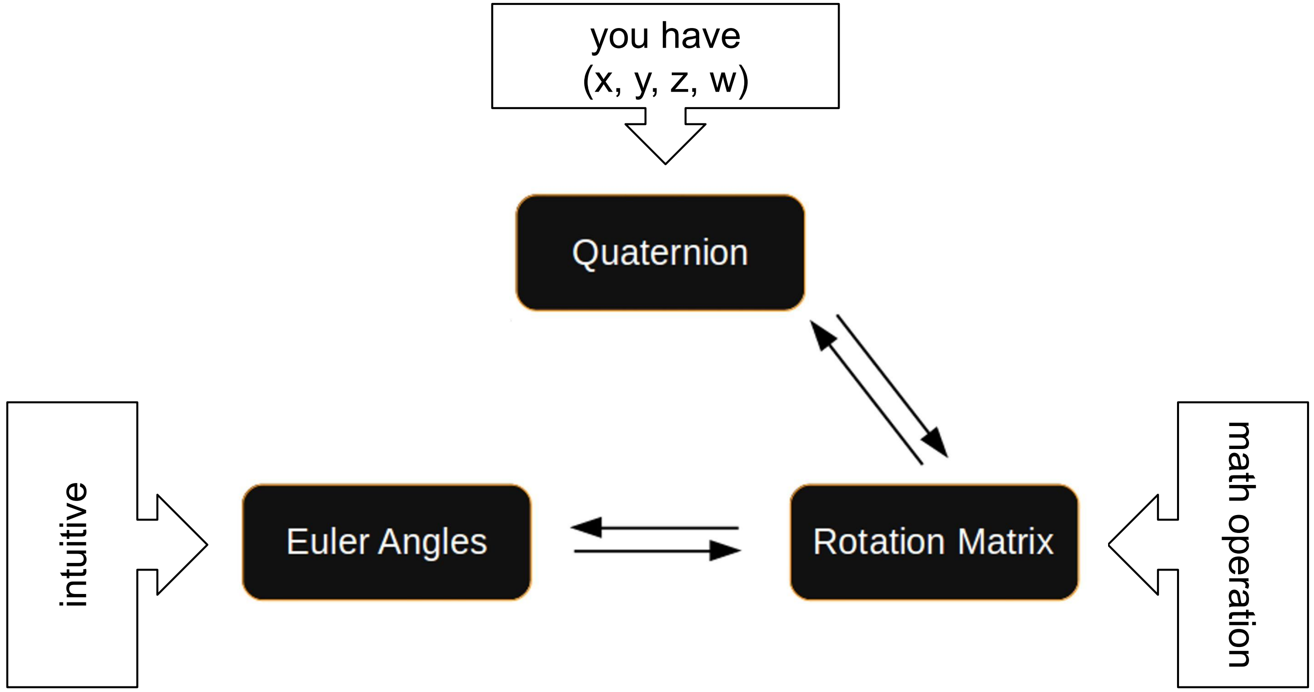
$$|\omega| = sqrt({\omega_h}^2 + {\omega_v}^2)$$


A
B
C
D
E
F
X-Coordinates
Y-Coordinates
Z-Coordinates
Density of Distances
Average Saccade Distances
Average Gaze Distances

What can you calculate based on that?

- spatial rotation (quaternion) ⇨ eular rotation angles





Example:

The plot displays the median distribution of gaze orientation degree at each time point throughout the experiment.