Head tracker using webcam for auralization

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1. Introduction
   - Motivation
2. The model
3. Results & Discussion
4. Conclusions

Outline

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Introduction: Binaural technology

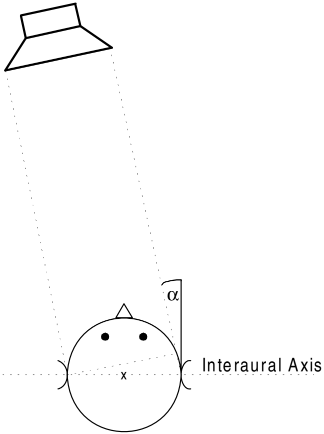

Figure 1: Adapted from Blauert [1].

Binaural Hearing:

- Natural listening;
- Consequence of having 2 ears;
- The **3D** acoustic perception of environments; and
- Allows sound sources **localization**.

Binaural technology

Head-related Transfer Functions (HRTFs)

- Transfer function of the **pathway** between a **sound source** and the **listener**'s ear canal.

Applications:

- 3D audio scenes on headphones and
- Virtual/augmented reality (VR/AR).

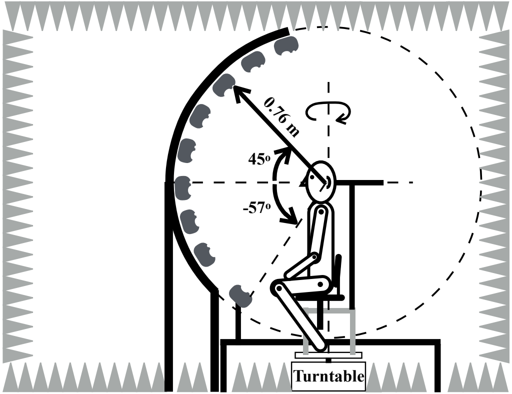

Figure 2: HRTF measurement setup [2].

Why use a head tracker?

Recording:

- Capture head movements during HRTF/BRIR measurements.

Reproducing:

- Real-world movement converted into virtual-world interaction.
  - Closer to natural perception than non-tracked auralizations;
  - Increased immersion to real-time rendered scenes; and
  - Correct source positioning in augmented reality (AR).

Head tracker in a binaural pipeline

- How to integrate a head tracker to a real-time auralization pipeline?

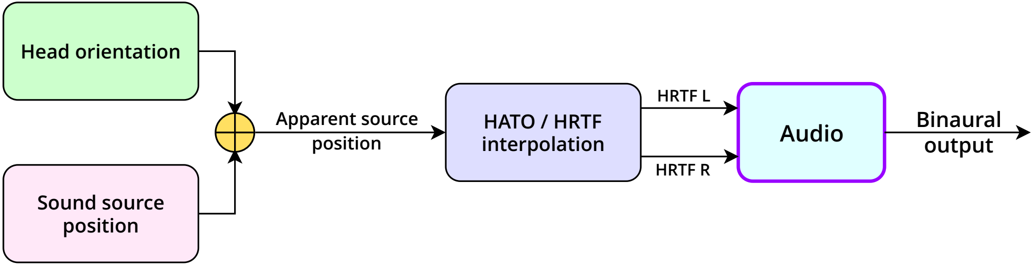

Figure 3: Simple auralization pipeline for binaural rendering with a head tracker.

Head tracker in a binaural pipeline

Hardware based

1. The sensor is usually mounted to the listener's head;

Software based

1. The sensor doesn't need to physically interact with the listener;

Head tracker in a binaural pipeline

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2. Not free (material costs);

Software based

1. The sensor doesn't need to physically interact with the listener;
2. Open to use (without cost);

Head tracker in a binaural pipeline

Hardware based

1. The sensor is usually mounted to the listener's head;
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3. Limits depend on the hardware; and

Software based

1. The sensor doesn't need to physically interact with the listener;
2. Open to use (without cost);
3. Limited to the camera opening angle; and

Head tracker in a binaural pipeline

Hardware based

1. The sensor is usually mounted to the listener's head;
2. Not free (material costs);
3. Limits depend on the hardware; and
4. It can be damaged.

Software based

1. The sensor doesn't need to physically interact with the listener;
2. Open to use (without cost);
3. Limited to the camera opening angle; and
4. Without planned obsolescence.

Outline

The model: Camera based approach

- Mediapipe's face mesh [3], a library for image AR (augmented reality):
  - Face detection and tracking via landmark identification.
- 468 landmarks.

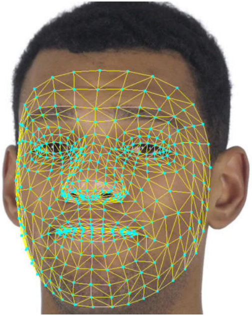


Figure 4: Face landmarks (adapted from [4]).

Camera based approach

- **34 out of the 468** landmarks are tracked
  - Face expressions influence and
  - Reduce processing overhead.

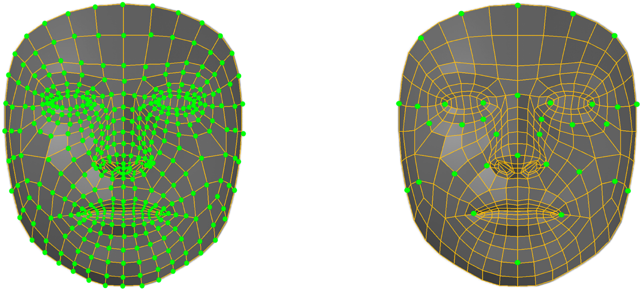


Figure 5: Comparison between 468 default landmarks and the 34 selected (adapted from [4]).

Camera based approach

- Rotational angles extracted from landmarks are necessary for the auralization.

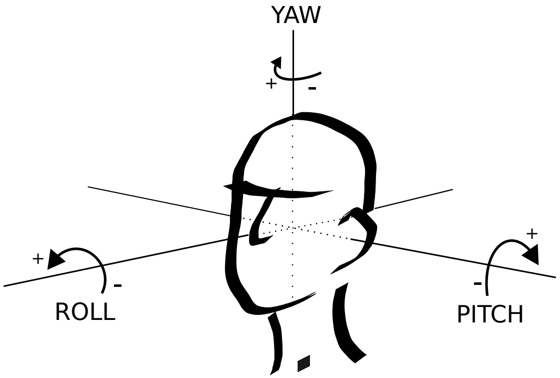


Figure 6: Yaw, pitch, and roll of the human head.

The model: Communication protocol

User datagram protocol (UDP)

- Continuous data stream;
- Low latency transmission; and
- Flexible message encoding.

Code 1: How to send data via UDP in Python.

```
import socket as skt
IP = '127.0.0.1'
PORT = 50050
s = skt.socket(skt.AF_INET, skt.SOCK_DGRAM)
coord = '{yaw},{pitch},{roll}'.format(yaw=-5,pitch=-2,roll=10)
s.sendto(coord.encode(), (IP,PORT))
```

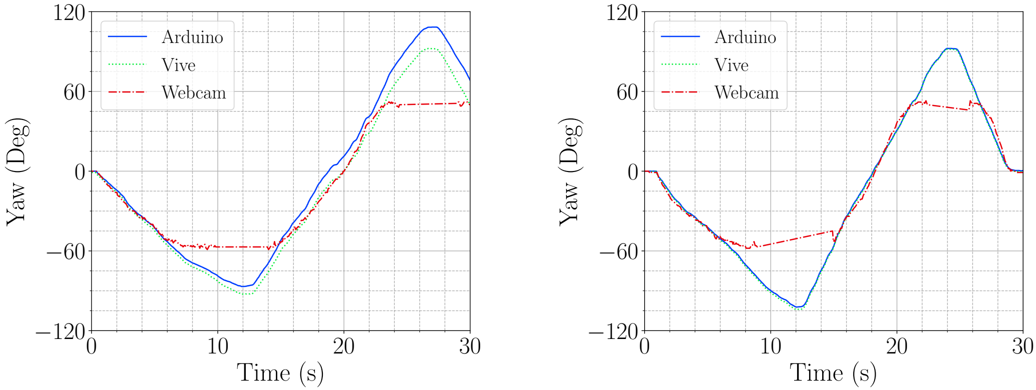
Outline

Results and Discussion: Hardware cross-validation

(a) Front view of the setup. (b) Rear view of the setup.

Figure 7: Neumann KU-100 with the three head trackers — the Arduino, Vive, and webcam.

Hardware cross-validation

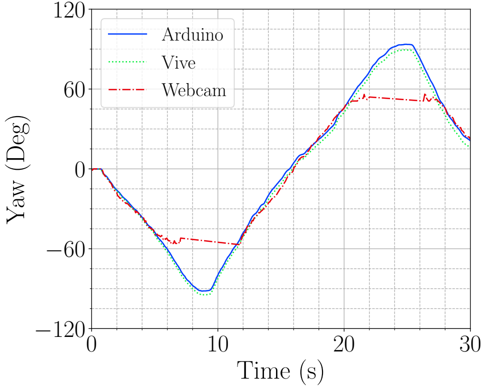


(a) Yaw Measurement 1.

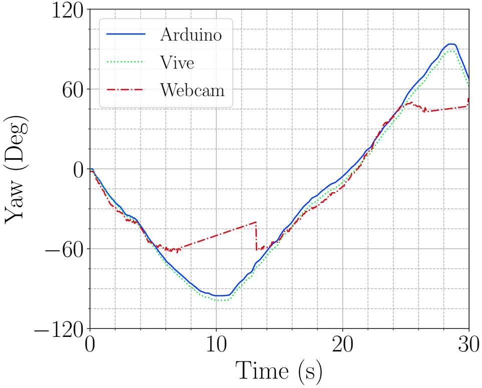
(b) Yaw Measurement 2.

Figure 8: Head tracker comparison for a yaw rotation, repeated measurements.

Hardware cross-validation



(a) Yaw Measurement 3.



(b) Yaw Measurement 4.

Figure 9: Head tracker comparison for a yaw rotation, repeated measurements.

Motion tracking amplitude

- **Real subject motion extension**

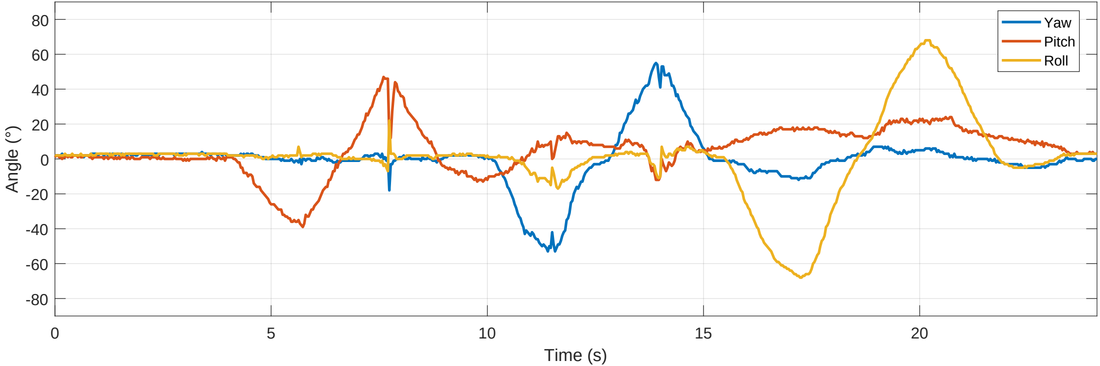


Figure 10: Head tracker motion extension measurement.

Results summary

Main characteristics:

- **Precision**: Good agreement with commercial hardware sensors;
- **Amplitude of motion tracking**:
  - Yaw $\approx 120°$;
  - Pitch $\approx 80°$; and
  - Roll: $360°$.
- **Resolution**: Truncated to $1°$ *(tunable)*;
- **Latency**: Yet to be determined.

Example: Real-time auralization

Videos

- https://youtu.be/k5Od8YP294A
- https://youtu.be/e_5j7NOdxMc

Outline

Conclusions

- **Comfortable, convenient and affordable solution** than hardware implementations;
- **Comparison to commercial hardware** head trackers, demonstrate **good agreement**;
- **Limited range of coverage angles**: suitable to applications where the user needs to keep looking at the screen at all times; and
- Flexible communication system: change message output format according to necessity.
- Additional data of this project can be found in the GitHub repository https://github.com/eac-ufsm/internoise2021-headtracker.

Future works

- Quantify system's latency;
- Explore the viability of expansion to a multi-camera system; and
- User friendly interface, including tweakable parameters.

Thank you!

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Amplifiers, Bolling Field, 1921.

Cite us!

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BibTeX: [5]

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@InProceedings{headtracker:2021,
  author    = {Davi Rocha Carvalho and William {\relax D'A}ndrea Fonseca and Jacob Hollebon and Paulo Henrique Mareze
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  booktitle = {{50th International Congress and Exposition on Noise Control Engineering - Internoise 2021}},
  title     = {Head tracker using webcam for auralization},
  year      = {2021},
  address   = {Washington, DC, USA},
  month     = {Aug.},
  pages     = {1--12},
}
```

References I

[1] Jens Blauert, ed. *Communication Acoustics*. Springer-Verlag Berlin Heidelberg, 2005. ISBN: 978-3540274377. DOI: 10.1007/b139075.

[2] Rahulram Sridharand, Joseph G. Tylka, and Edgar Choueiri. "A database of head-related transfer function and morphological measurements". In: *143rd AES Convention*. New York, NY, USA, Oct. 2017, pp. 1–5. URL: https://www.aes.org/e-lib/browse.cfm?elib=19308.

[3] Camillo Lugaresi, Jiuqiang Tang, Hadon Nash, Chris McClanahan, Esha Uboweja, Michael Hays, Fan Zhang, Chuo-Ling Chang, Ming Guang Yong, Juhyun Lee, Wan-Teh Chang, Wei Hua, Manfred Georg, and Matthias Grundmann. "MediaPipe: A Framework for Building Perception Pipelines". In: *CoRR* abs/1906.08172 (2019). URL http://arxiv.org/abs/1906.08172 or https://github.com/google/mediapipe. arXiv: 1906.08172.

[4] Yury Kartynnik, Artsiom Ablavatski, Ivan Grishchenko, and Matthias Grundmann. "Real-time Facial Surface Geometry from Monocular Video on Mobile GPUs". In: *CoRR* abs/1907.06724 (2019). arXiv: 1907.06724. URL: http://arxiv.org/abs/1907.06724.

References II

[5] Davi Rocha Carvalho, William D'Andrea Fonseca, Jacob Hollebon, Paulo Henrique Mareze, and Filippo Maria Fazi. "Head tracker using webcam for auralization". In: *50th International Congress and Exposition on Noise Control Engineering - Internoise 2021*. Washington, DC, USA, Aug. 2021, pp. 1–12.