Respiratory Rate Monitoring from Earables

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The RR-Ear design strives to enable *portable*, *unobtrusive*, *continuous* and *accurate* respiration rate (RR) monitoring which can *seamlessly* work under different conditions of daily life. Specifically, RR-Ear can achieve robust RR monitoring under stationary scenarios with motion artifacts, *e.g.,* from lying at rest to in-the-wild working in an office, and active scenarios, *i.e.,* walking and running.

Earables are utilized in RR-Ear to fulfill such needs because of their portability, universality and superior sensing position. Existing works for RR monitoring from earables have achieved the initial success under certain conditions that the user is stationary and has conscious (*i.e.,* controlled) or strong breath [RWL+19, RAA+21, KMO+21, MV17]. However, since they focus on investigating either *visible* respiration-incurred motions captured via the IMUs on earphone [RWL+19, RAA+21], or *audible* respiration sounds captured via the outward-facing or inward-facing microphone on earphone [KMO+21, MV17], when the user's breath is unconscious (*i.e.,* uncontrolled and in-the-wild) or under moving scenarios, such visible motions and audible sounds would be too weak to detect or overwhelmed by motion signals, leading to unreliable RR monitoring. Therefore, there are still gaps in RR monitoring from earables to make it works under more generalized conditions of daily life, and RR-Ear is proposed to make such gaps much closer.

Compared with existing works focusing on RR estimation using captured respiration signals only, *i.e.,* the *visible/audible* respiration-incurred motions/sounds [RWL+19, RAA+21, KMO+21, MV17], the key novelty of RR-Ear design is to comprehensively investigate the relationships between RR and kinds of captured physiological signals from earables when the user is breathing under different conditions. Therefore, when the respiration signals are weak or overwhelmed by motion signals, RR-Ear can automatically select another kind of high-quality physiological signals to estimate RR, which can effectively avoid unreliable estimation.

In particular, we recognize the inward-facing microphone on earphone as the sensing modality in RR-Ear on account of its good sealing of ear canal to block external noises and amplify low-frequency sounds (*i.e.,* occlusion effect [MFM21]), availability on kinds of commercial earphones, *e.g.,* AirPods Pro [Air23], and especially the inner-body bone and air conduction to capture kinds of body sounds not limited to respiration when the user is breathing, *e.g.,* heart rate, stride, *etc.*. We find that such body sounds are exactly in the right place to have different coupling relationships with RR under different conditions.

References

[Air23] Airpods pro. `https://www.apple.com/airpods-pro/specs/`, 2023.

[KMO+21] Agni Kumar, Vikramjit Mitra, Carolyn Oliver, Adeeti Ullal, Matt Biddulph, and Irida Mance. Estimating respiratory rate from breath audio obtained through wearable microphones. In *2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, pages 7310–7315. IEEE, 2021.

[MFM21] Dong Ma, Andrea Ferlini, and Cecilia Mascolo. Oesense: employing occlusion effect for in-ear human sensing. In *Proceedings of the 19th Annual International Conference on Mobile Systems, Applications, and Services*, pages 175–187, 2021.

[MV17] Alexis Martin and Jérémie Voix. In-ear audio wearable: Measurement of heart and breathing rates for health and safety monitoring. *IEEE Transactions on Biomedical Engineering*, 65(6):1256–1263, 2017.

[RAA$^+$21] Md Mahbubur Rahman, Tousif Ahmed, Mohsin Yusuf Ahmed, Ebrahim Nemati, Minh Dinh, Nathan Folkman, Md Mehedi Hasan, Jilong Kuang, and Jun Alex Gao. Towards motion-aware passive resting respiratory rate monitoring using earbuds. In *2021 IEEE 17th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*, pages 1–4. IEEE, 2021.

[RWL$^+$19] Tobias Röddiger, Daniel Wolffram, David Laubenstein, Matthias Budde, and Michael Beigl. Towards Respiration Rate Monitoring Using an In-Ear Headphone Inertial Measurement Unit. In *Proceedings of the 1st International Workshop on Earable Computing*, pages 48–53, London United Kingdom, September 2019. ACM.