Where should we put wearable batteries for better usability?

Jiwon Kim
Dept. of Industrial Design, KAIST
jiwonder@kaist.ac.kr

Andrea Bianchi
Dept. of Industrial Design, KAIST
andrea@kaist.ac.kr

Abstract

Wearable electronics are becoming crucial tools for everyday life. Therefore, interest in powering those devices is also increasing. However, the dimension of the wearable battery's location was not reviewed thoroughly, despite its importance in user experience. Therefore, we propose a taxonomy of the location of the batteries of wearable devices through a literature review.

Keyword
Wearable battery location, User experience, Literature review

1. Introduction

The importance of wearable devices is increasing these days. According to a market research, the wearable market's compound annual growth rate was estimated at 25.91 percent from 2021 to 2028 [24]. Moreover, 3 of every 5 wearable device owners use it daily [6]. Therefore, the battery's wearability and charging are also becoming significant factors to consider when choosing wearables.

Recent previous works were about powering wearables (e.g., the performance of batteries [1] and energy harvesting [8, 13]), but there was no survey of how manufacturers or researchers power their wearables. However, it is worth classifying since the location of batteries severely affects the wearability of the device and its charging.

This paper was motivated by the following research question: **"Where should we put wearable batteries for better usability?".** To answer the question, we propose a survey and classification of wearable batteries and their locations.

2. Related Work

Previous works focused on describing the space by providing surveys of various wearables [10, 18]. Some surveys also discussed the type of sensors used in wearables, which range from heart sensors [11] to light, force, sound, and location sensors [7].

Still, we could not find a study reviewing the dimension of location regarding the batteries of wearable devices.

3. Review Methodology

3.1 Data collection

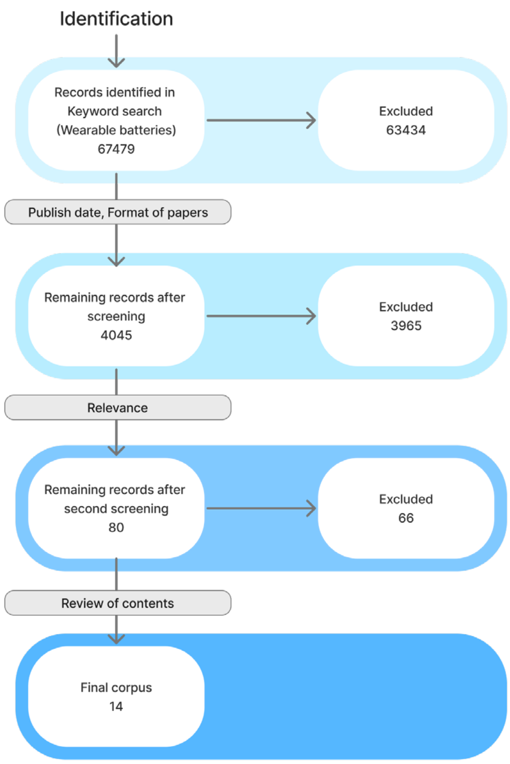

fig. 1 PRISMA chart

For the data collection, we identified 67479 records from ACM digital library. Then, we found 14 highly relevant research articles from various journals through PRISMA diagram (see fig.1). We selected papers that explain their unique wearable hardware while excluding studies about developing algorithms for existing wearable devices. For further insight, we also referred to battery location data from existing wearable products within five years (e.g., Apple Watch9, Galaxy watch6).

3.2 Data analysis

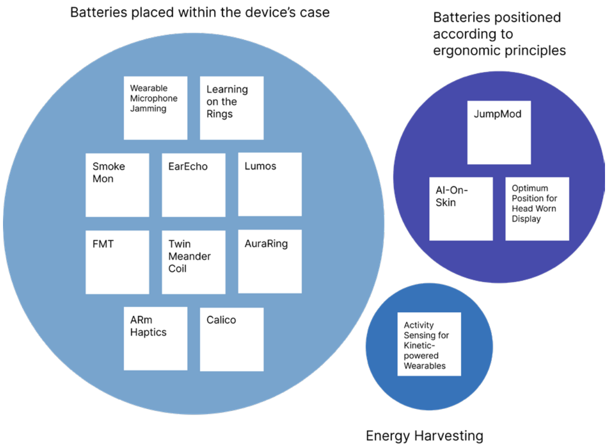

fig. 2 Affinity diagram of 14 selected papers

We analyzed the advantages and disadvantages of the location of the device's battery and conducted thematic coding with 14 selected papers. Then, we created an affinity diagram to visualize (see fig. 2). As a result, we suggest three types of battery locations.

3.3 Results

3.2.1 type 1: Batteries placed within the device's casing

In type 1, batteries are kept inside the device's case, so no power cable is exposed. Due to space limitations, lithium-ion or lithium polymer batteries (12mAh-1000mAh) are frequently used in commercial wearables and prototypes. The batteries are usually lightweight (around 2.4g~22.3g) and small (around 3.9mm * 14mm * 30 mm~3.8 mm * 38mm * 75mm) [16] with a form factor of the wrist-wearing device. We classified most wrist-wearing wearables in the market as type 1. (e.g., Galaxy watch6, Apple watch9, Garmin forerunner 265, Xiaomi smart band8). In addition, we categorized the majority (10 out of 14) of selected papers as type 1. However, the capacity of these batteries needed to be increased for some of the devices to run a day (e.g., SmokeMon: 19 hours [2], Lumos: 5 hours [23]), which implies those devices will need frequent charging. Even commercial smartwatches need to be charged at least once every 2 to 3 days [4]. However, adapting batteries with sufficient capacities in type 1 is challenging. This is because the increase in battery size and weight means the device is to be bulky, which leads to a drop in usability.

3.2.2 type 2: Batteries positioned according to ergonomic principles

For usability, type 2 devices consider human factors like the structure of the human body or fatigue from the device's weight. We classified 3 out of 14 selected papers as type 2. In this case, power cables are likely to be exposed, and sometimes batteries are separated from the device and located in a particular position of the body. Unlike type 1, fewer size, location, and battery weight limitations exist. (e.g., Jumpmod: battery pack's weight was about 2kg [19]) Therefore, the battery pack can counterbalance the device's or user's weight. (e.g., Meta Quest 3's battery is on the opposite side of the display for the counterbalance [17].)

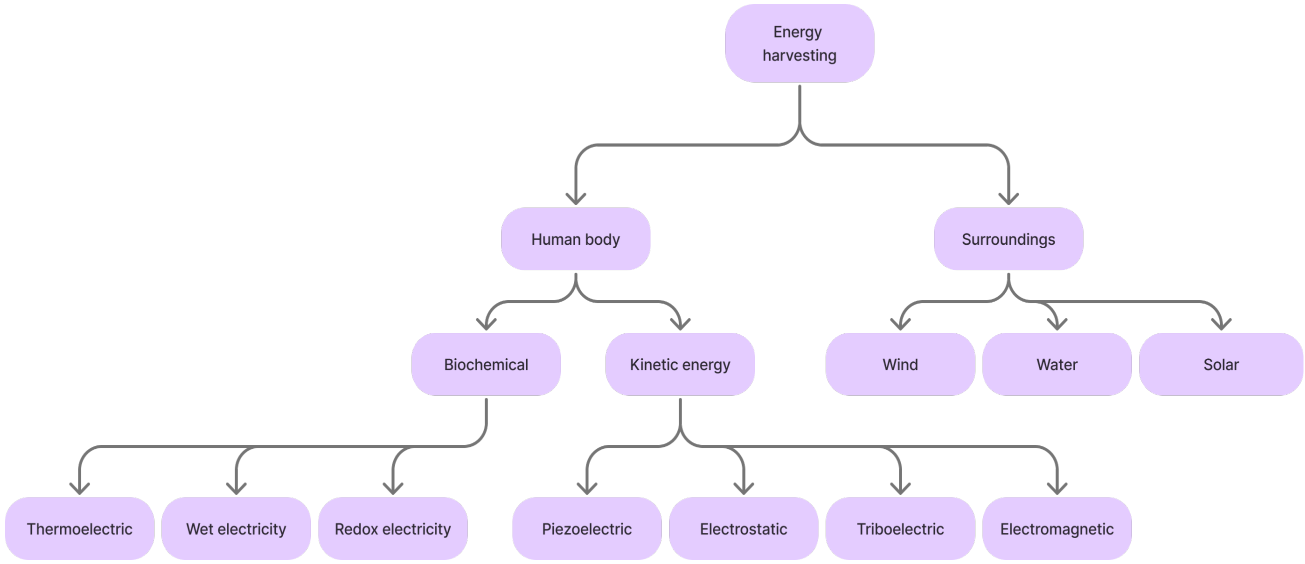

fig. 3 Energy harvesting techniques for the wearables [25, 3]

Although there are fewer limitations about the battery's form, type 2 devices still use lithium-based batteries.

3.2.3 type 3: Energy harvesting

In case of lithium-based batteries, it has limited usage time per charge. However, wearable devices can harvest energy from their surroundings and users without batteries (see Table. 1). Energy harvesting is eco-friendly compared to the lithium-based batteries since it needs no charging and reduces the disposal of batteries [21]. In the literature, they mainly discussed harvesting the kinetic energy from the human body (KEH). (e.g., sensing location with passive RFID [13], using KEH transducers [12]) However, KEH including insole-based kinetic energy harvesting supplies low battery power (1.1-1.7mw, 10-20µJ) [15], which is not

	Type 1. Batteries placed within the device's casing	Type 2. Batteries positioned according to ergonomic principles	Type 3. Energy harvesting
Features	Lithium-ion or polymer batteries (12mAh-1000mAh) are frequently used in both commercial wearables and prototypes, with a form factor of wrist-wearing devices (e.g., Apple watch 9)	Various battery sizes and capacities are used compared to type 1. Can use the battery to counterbalance the device's weight or the user's action.	Harvesting the kinetic energy of the human body is mainly discussed. (e.g., sensing location with passive RFID, or using KEH transducers)
Advantages	Relatively light-weighted compared to type 2. No obstructing power cable.	Fewer limitations in size, location, and weight of the battery.	Eco friendly. No charging.
Disadvantages	Difficult to deal with power-hungry modules, Frequent charging (at least once in 2-3days)	The power cable might be obstructing	Low battery power
Examples	Galaxy watch6, Apple watch9, SmokeMon, Lumos	Meta quest 3, JumpMod	Seiko kinetic watch

Table. 1 Taxonomy of 3 types of battery locations

sufficient for Bluetooth and Wi-Fi modules [20]. We classified 1 out of 14 selected papers as type 3. Even though there was insufficient paper about energy harvesting wearables, a commercial example for type 3 existed from Seiko that incorporated kinetic harvesting into a watch. The movement of the user's wrist or the rotation of the watch's crown generates energy [14].

4. Discussion

4.1 Growing attention about energy harvesting wearables

Energy harvesting technologies are in the limelight. As shown in Chapter 3.2.3, there are active discussions about energy harvesting technologies for wearables in the academic field [15]. Also, wireless energy harvesting (WEH) enables charging for power-hungry modules like Bluetooth [9]. Therefore, we assume that the future of using completely charge-free wearable devices is not far by combining WEH and other energy harvesting technologies like kinetic energy harvesting.

4.2 Battery as an Advantage

In some cases, batteries make a device more advantageous. For example, in Jumpmod, users jump better because the battery pack serves two functionalities: providing power and counterbalancing the weight from the user while jumping. Like Jumpmod, it is helpful to develop an alternative role of a battery to transform it into an advantage. Nowadays, battery researchers are developing a new type of flexible battery, which gives a new form to rigid wearable casings [22]. This battery will open a new chapter of wearable designs, allowing device flexibility.

4.3 Social acceptability of battery's locations

Throughout the literature, there was a considerable amount of novel wearable interfaces [2, 19]. However, wearing it might be socially awkward, depending on the battery's location and form. For instance, AI-on-skin [5] puts its battery on the user's upper arm, which might be unfamiliar for locating wearable batteries. However, social acceptability changes as new technologies prevail. To explain, wearing Bluetooth earphones is natural these days, while it was not 20 years ago. Therefore, we expect the social acceptability of locating batteries to grow as novel wearing interfaces appear in the future.

5. Conclusion

Throughout the research, we collected location data of wearable devices from literature and wearable product data and classified them through thematic coding. As a result, we suggest three different aspects according to the battery's location to construct the taxonomy about the battery's location. Through these studies, our work aspires to be a starting point to discuss optimal battery locations for wearable devices.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A5A7025409).

References

1. Mohit Agarwal and Raghupathy Sivakumar. 2020. Charge for a whole day: Extending Battery Life for BCI Wearables using a Lightweight Wake-Up Command. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20). Association for Computing Machinery, New York, NY, USA, 1-14. https://doi.org/10.1145/3313831.3376738

2. Rawan Alharbi, Soroush Shahi, Stefany Cruz, Lingfeng Li, Sougata Sen, Mahdi Pedram, Christopher Romano, Josiah Hester, Aggelos K. Katsaggelos, and Nabil Alshurafa. 2023. SmokeMon: Unobtrusive Extraction of Smoking Topography Using Wearable Energy-Efficient Thermal. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 6, 4, Article 155 (December 2022), 25 pages. https://doi.org/10.1145/3569460

3. Ahsan Ali, Hamna Shaukat, Saira Bibi, Wael Altabey, Mohammad Noori, Sallam Kouritem,

Recent progress in energy harvesting systems for wearable technology, Energy Strategy Reviews, Volume 49, 2023, 101124, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2023.101124
4. Apple Watch - Battery. Apple. https://www.apple.com/watch/battery/.
5. Ananta Narayanan Balaji and Li-Shiuan Peh. 2023. AI-On-Skin: Towards Enabling Fast and Scalable On-body AI Inference for Wearable On-Skin Interfaces. Proc. ACM Hum.-Comput. Interact. 7, EICS, Article 187 (June 2023), 34 pages. https://doi.org/10.1145/3593239
6. Jeff Beckman. (2023, August 17). 15 Wearable Technology Statistics [2023 edition]. The Tech Report. https://techreport.com/statistics/wearable-technology-statistics/#:~:text=Wearable%20Technology%20Sales,-5.&text=2022%20showed%20the%20number%20of,billion%20people%2C%20and%20sales%20increased
7. Jorge Blasco, Thomas Chen, Juan Tapiador, and Pedro Peris-Lopez. 2016. A Survey of Wearable Biometric Recognition Systems. ACM Comput. Surv. 49, 3, Article 43 (September 2017), 35 pages. https://doi.org/10.1145/2968215
8. Christine Dierk, Molly Jane Pearce Nicholas, and Eric Paulos. 2018. AlterWear: Battery-Free Wearable Displays for Opportunistic Interactions. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, Paper 220, 1-11. https://doi.org/10.1145/3173574.3173794
9. Energy harvesting for battery-free bluetooth devices. Wiliot. 2023, July 17. https://www.wiliot.com/what-is-energy-harvesting-for-bluetooth-devices
10. Yanglei Gan, Tianyi Wang, Alireza Javaheri, Elaheh Momeni-Ortner, Milad Dehghani, Mehdi Hosseinzadeh, and Reza Rawassizadeh. 2021. 11 Years with Wearables: Quantitative Analysis of Social Media, Academia, News Agencies, and Lead User Community from 2009-2020 on Wearable Technologies. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5, 1, Article 11 (March 2021), 26 pages. https://doi.org/10.1145/3448096
11. Meaghan Harraghy, Diane Calderon, Rebecca Lietz, James Brady, Fillia Makedon, and Eric Becker. 2019. A review of wearable heart rate sensors in research. In Proceedings of the 12th ACM International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '19). Association for Computing Machinery, New York, NY, USA, 315-316. https://doi.org/10.1145/3316782.3321550
12. Qianyi Huang, Yan Mei, Wei Wang, and Qian Zhang. 2018. Toward Battery-Free Wearable Devices: The Synergy between Two Feet. ACM Trans. Cyber-Phys. Syst. 2, 3, Article 20 (July 2018), 18 pages. https://doi.org/10.1145/3185503
13. Haojian Jin, Zhijian Yang, Swarun Kumar, and Jason Hong. 2018. Towards Wearable Everyday Body-Frame Tracking using Passive RFIDs. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 1, 4, Article 145 (December 2017), 23 pages. https://doi.org/10.1145/3161199
14. Kinetic Direct Drive. Seiko Watch Corporation. https://www.seikowatches.com/kr-ko/customerservice/knowledge/kinetic-direct-drive-knowledge.
15. Guohao Lan, Dong Ma, Weitao Xu, Mahbub Hassan, and Wen Hu. 2020. Capacitor-based Activity Sensing for Kinetic-powered Wearable IoTs. ACM Trans. Internet Things 1, 1, Article 2 (February 2020), 26 pages. p22https://doi.org/10.1145/3362124
16. Lithium polymer battery pack, lithium polymer cell, Li Po battery pack, Protection Circuit. (n.d.).http://www.ibt-power.com/Battery_packs/Li_Polymer/Lithium_polymer_cells.html
17. Meta Quest 3 Elite Strap with Battery. Meta. https://www.meta.com/kr/en/quest/accessories/quest-3-elite-strap-battery/.
18. Troy Nachtigall, Daniel Tetteroo, and Panos Markopoulos. 2018. A five-year review of methods, purposes and domains of the international symposium on wearable computing. In Proceedings of the 2018 ACM International

Symposium on Wearable Computers (ISWC '18). Association for Computing Machinery, New York, NY, USA, 48-55. https://doi.org/10.1145/3267242.3267272

19. Romain Nith, Jacob Serfaty, Samuel Shatzkin, Alan Shen, and Pedro Lopes. 2023. Demonstrating JumpMod: Haptic Backpack that Modifies Users' Perceived Jump. In ACM SIGGRAPH 2023 Emerging Technologies (SIGGRAPH '23). Association for Computing Machinery, New York, NY, USA, Article 7, 1-2. https://doi.org/10.1145/3588037.3595387

20. Power consumption test for Bluetooth, ZigBee, and Wi-Fi. https://www.researchgate.net/figure/Power-Consumption-Test-for-Bluetooth-ZigBee-and-Wi-Fi_tbl1_318054538.

21. Thomas Søderholm, June 7, 2023. Energy harvesting shows the way to a sustainable future. https://blog.nordicsemi.com/getconnected/energy-harvesting-shows-the-way-to-a-sustainable-future#:~:text=Limiting%20environmental%20impact&text=Such%20advances%20make%20it%20feasible,introduces%20a%20more%20sustainable%20option

22. Top 10 emerging technologies of 2023 report. World Economic Forum. (n.d.). https://www.weforum.org/publications/top-10-emerging-technologies-of-2023/in-full/flexible-batteries/

23. Amanda Watson, Claire Kendell, Anush Lingamoorthy, Insup Lee, and James Weimer. 2023. Lumos: An Open-Source Device for Wearable Spectroscopy Research. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 6, 4, Article 187 (December 2022), 24 pages. https://doi.org/10.1145/3569502

24. Wearable Electronics Market Size, share, Opportunities & Forecast. Verified Market Research. (2022, October 13). https://www.verifiedmarketresearch.com/product/wearable-electronicsmarket/?gclid=Cj0KCQjw-pyqBhDmARIsAKd9XINgG3LdVnDBSBbRRlrtWu1exDliTy63wa78MP0zwSbAW5jkN_dkHoEaAqh-EALw_wcB

25. Chen Xu, Yu Song, Mengdi Han et al. Portable and wearable self-powered systems based on emerging energy harvesting technology. Microsyst Nanoeng 7, 25 (2021). https://doi.org/10.1038/s41378-021-00248-z