ScentEcho: Exploring Adsorbent Materials for Accurate Odor Collection and Playback

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ABSTRACT

Odor collection and playback have garnered significant attention in recent olfactory interface research due to their critical role in enhancing immersive experiences and emotional connections. To address these needs, we developed ScentEcho, a compact and portable device for rapid scent storage and playback, supporting four odor storage units with mobile charging. Through subjective evaluations from 12 users and GC-MS analysis, we assessed eight adsorbent materials for capturing and replaying mint, lemon, lavender, and coffee bean. Results showed Carbopack C excelled in maintaining odor similarity, with a strong correlation (r = 0.805) between perceived intensity and similarity. This study highlights the importance of adsorbent materials in high-fidelity scent playback and supports olfactory applications in multisensory interaction.

CCS CONCEPTS • **Human-centered computing** → **Human computer interaction (HCI)**; *HCI design and evaluation methods*; **Laboratory experiments**;

Additional Keywords and Phrases: Odor collection; Adsorbent materials; GC-MS analysis; Odor perception

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1 INTRODUCTION

In daily life, vision and hearing account for about 90% of our sensory input [14], while the sense of smell occupies a smaller proportion, it has a unique ability to evoke emotions and memories[15]. Leveraging this characteristic, HCI (Human-Computer Interaction) research explores how integrating smell can create more immersive experiences and enhance user engagement [1, 4, 18, 23]. For instance, preferred scents, such as light floral fragrances or the stability of woody aromas, have been shown to enhance efficiency and satisfaction during computer-based tasks [12].

However, current systems often rely on pre-defined odors [5, 32], such as preset fragrances like the smell of roses, which may not align with individual perceptions and memories. While some studies enable users to create personalized mixtures by adjusting proportions of base compounds [8, 24], these methods are limited by the fixed source materials, reducing creative flexibility and compromising the authenticity of recreated scents. To address these challenges, one potential solution is to allow users to collect and customize scents directly from their surroundings. Traditional scent collection techniques, such as hydrodistillation or solvent extraction [2, 9, 19], remain time-consuming, equipment-intensive, and unsuitable for portable or personal use. Although innovative concepts like the "smell camera" [17] attempt to capture and release scents, drawbacks such as bulkiness, single-use capacity, and limited substance variety continue to hinder their practicality. To develop a practical and efficient scent collection device, it is essential to evaluate materials that can effectively adsorb and release a wide range of odor compounds.

In this study, we evaluate different adsorption materials, also referred to as odor storage units, to identify their effectiveness in capturing and releasing scents commonly studied in HCI, such as lemon, coffee bean, mint, and lavender.

Participants assess the similarity and intensity of the released scents, while chemical analysis of these sources helps identify which adsorption materials show better suitability for specific odor compounds among those tested. By combining subjective evaluations with objective chemical data, we aim to establish a foundation for high-fidelity scent capture and playback.

Building on these findings, we developed ScentEcho, a portable device that empowers users to collect scents they find intriguing and share them with others, bridging the gap for odors that are difficult to describe in words. By integrating personal and social value with applications in HCI, ScentEcho demonstrates its potential as a versatile tool for advancing olfactory experiences.

2 RELATED WORK

Olfaction has gained significant attention in Human-Computer Interaction (HCI), with research focusing on its integration with other sensory modalities to create immersive and emotionally engaging user experiences.[10, 16, 29, 30]. However, most existing studies rely on commercially available sources such as perfumes, fragrances, or essential oils [4, 6, 8, 18, 31]. While these sources are convenient, their labels or descriptors often fail to accurately reflect olfactory perception, leading to discrepancies between descriptions and actual experiences. A high-fidelity approach to capturing and reproducing specific odors could not only enhance the accuracy and diversity of scent applications but also enable users to personalize and share unique olfactory experiences. This would facilitate emotional connections and improve communication by conveying sensations that are difficult to express through words.

High-fidelity scent collection also has the potential to capture unique and familiar odors from everyday life, offering psychological benefits. Research has shown that familiar odors can significantly reduce stress, such as calming newborns or alleviating adult anxiety while improving overall well-being. This underscores the importance of precise odor capture and reproduction, which can unlock new possibilities in olfactory interaction design and improve quality of life.

Previous work by designers and companies has introduced concepts for scent collection using methods such as solvent extraction or adsorbent-based techniques to capture target odors, addressing user needs for unique and high-fidelity scents [21, 22, 26]. Additionally, studies have proposed camera-like physical odor capture devices, employing simple air bags to collect scents and release them by compressing the air, exploring potential application scenarios and user feedback. The fidelity of these systems—whether the reproduced scent retains the same characteristics as the captured scent—is a critical factor that determines whether users can resonate with the recreated odors. However, studies specifically addressing the fidelity of recreated odors remain limited.

This research focuses on the performance of various adsorbents in capturing odors from different sources and identifying the most effective materials for achieving optimal results. Common adsorbents used in environmental gas analysis were selected for this study, as they are widely employed for outdoor sampling and subsequent laboratory analysis but are rarely examined in the context of human olfactory perception. These materials also support self-cleaning through purging, allowing for reuse. By selecting high-performance adsorbents and integrating them into the design of ScentEcho, this study aims to provide a portable tool for personalized scent collection with high fidelity and convenience, enabling diverse applications in HCI scenarios.

3 DESIGN AND IMPLEMENTATION

ScentEcho is composed of two separate compartments: the upper compartment, which houses the electronic components and serves as the control unit, and the lower compartment, which contains four independent odor storage units, forming the device's core functional component. Figure 1 illustrates the overall structure and operation of ScentEcho.

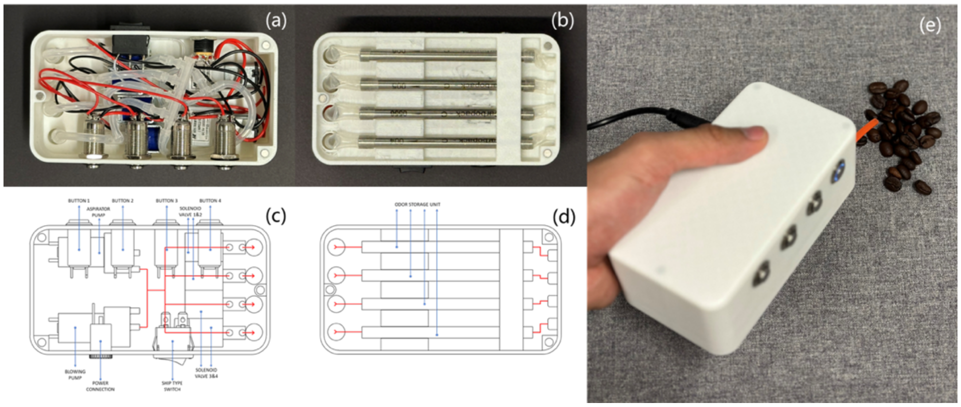

Figure 1: Illustrations of the Device Structure and Operation (a) Internal view of the upper compartment. (b) Internal view of the lower compartment. (c) Schematic of the upper compartment structure and pneumatic pathways. (d) Schematic of the lower compartment structure and pneumatic pathways. (e) Schematic of the odor collection process

The upper compartment includes four self-locking buttons, a three-position toggle switch, and a power connection. It houses two air pumps (5V, 1.1 L/min) for odor collection and playback. To ensure pump longevity and odor delivery stability, a toggle switch ensures only one pump operates at a time. Four two-way solenoid valves (5V) are individually controlled by self-locking buttons. For ease of maintenance, the lower compartment features only the odor storage units and support structures. Magnets connect the upper and lower compartments, facilitating easy inspection and replacement. Figure 1(a) and 1(b) detail the internal structure of the compartments.

The pneumatic system is depicted in Figure 1(c) and 1(d), with red lines indicating airflow. Air pumps provide the driving force, and solenoid valves control specific pathways. Two pumps connect to four solenoid valves via three-way and four-way connectors, and these valves are linked to the odor storage units in the lower compartment through air hoses. Users operate the device by pressing one or more self-locking buttons to activate the corresponding solenoid valves, followed by toggling the switch to start the aspirator or blowing pump for odor collection or playback. Backlit buttons provide visual feedback, indicating the active odor storage unit, as shown in Figure 1(e).

ScentEcho offers several key advantages: 1. Odor Collection and Playback, it can manage four different odors simultaneously, with reserved space in the lower compartment for additional storage units, enabling expansion; 2. Compact Design and Maintenance, the device's small size (127×68×47 mm), light weight (248 g), and simple structure make it easy to operate and maintain with one hand. 3. Simple Controls, no programming or integrated circuits are required, as functionality is managed by four buttons and a toggle switch, ensuring user-friendliness. 4. Portability and Power Supply, although it lacks a built-in battery, the device is designed to connect to a power bank via a simple adapter, with all components running on a 5V power supply.

After implementation, ScentEcho was employed to evaluate and select suitable adsorption materials for its odor storage units. The device's efficient and user-friendly design proved highly effective for testing the performance of different materials in capturing and replaying various odors.

4 DESIGN AND IMPLEMENTATION

This study evaluates the performance of different adsorbent materials in capturing odorants, primarily through user experiments on the similarity and intensity of reproduced odors. GC-MS analysis of target odors complements these findings, offering insights into the relationship between adsorbent properties and sensory evaluations.

4.1 Methodology and Procedure

This study evaluates the collection and playback performance of various adsorbent materials for odorants. The selected odorants, commonly used in HCI research, include lemon, coffee beans, mint, and lavender [3, 7, 11, 13, 20], all purchased from local markets. Coffee beans and lavender were stored at room temperature (25°C), while fresh lemons and mint leaves were refrigerated at -4°C. Before the experiments, refrigerated samples were brought to room temperature for adsorption. The specifications of adsorbent materials were listed in Table 1. The materials were packed into stainless steel tubes (outer diameter: 6 mm, length: 90 mm) with a particle size of 60-80 mesh and a loading amount of 200 mg. Before use, the adsorption tubes were purged at 250°C for 30 minutes and cooled to room temperature.

Table 1: Specifications of adsorbent materials used in this study

Code	Type	Supplier's Note
A	Tenax TA	C7-C26[a]
B	Carbopack B	C5-C12
C	Carbopack C	C12-C20
D	Carbopack X	C3-C6
E	Carboxen 1000	C2-C5
F	Si gel-CN	Hydrocarbons, CO, CO2, Sulfur-containing gases
G	AC	-
H	T-CXmix	Tenax TA + Carbopack X

[a] Carbon number range of substances suitable for adsorption.

All experiments were conducted under controlled conditions of 25±2°C and 50±10% relative humidity. Prior to the experiment, all participants signed an informed consent form, indicating their understanding of the experiment's procedure and their right to withdraw at any time. Both odor collection and playback were conducted using the ScentEcho device. During odor collection, the target odors (lemon, coffee beans, mint, and lavender) were adsorbed onto the selected adsorbent materials (A-H). The collection time was set to 1 minute, with minor adjustments based on a study by Lu et al. [17] investigating acceptable durations for odor collection. Then, participants were exposed to the reproduced odors (playback) and asked to rate their similarity and intensity relative to the target odors using a Likert scale [27, 28], where the target odor was defined as 7 points (1 = completely dissimilar or no odor; 7 = identical to the target). To account for individual differences and scoring biases, the ratings were also standardized using Z-scores (Equation 1)[25]. where Z represents the Z-score, X represents the original value, μ represents the mean, and σ represents the standard deviation. To evaluate the relationship between odor similarity and intensity ratings, the Pearson Correlation Coefficient γ was used to assess the relationship between odor similarity and intensity, calculated as Equation 2, Where, X and Y represent similarity and intensity ratings, while $\bar{X}$ and $\bar{Y}$ are their means.

$$\frac{z = X - b}{\sigma} \quad (1) \qquad \frac{\gamma = \Sigma(X-\bar{X})(Y-\bar{Y})}{\sqrt{\Sigma(X-\bar{X})^2(Y-\bar{Y})^2}} \quad (2)$$

Participants were instructed to rate the reproduced odors within 10 s and were allowed to re-smell the target odor as needed (Figure 2). The rating form (Appendix 1) collected personal information and scoring data, as well as responses to questions such as: “Do you regularly use perfumes or fragrance-related products?” and “Do you consider yourself to have a keen sense of smell?” Additionally, exploratory questions were posed during the experiment to further investigate participants’ perceptions. These included: “Can you independently evaluate the similarity and intensity of an odor?” and “At what similarity score do you feel confident in identifying the odor source without needing to see the actual object?” The experiment consisted of two main stages. Odor preparation, including collection and playback setup, required approximately 40 minutes. And participant evaluations took an additional 30 minutes. To minimize fatigue and ensure accuracy, a 3-minute rest period was provided between exposure to different target odors, including lemon, coffee beans, mint, and lavender.

Figure 2: A participant using ScentEcho to evaluate odor similarity and intensity.

4.2 Odor Analysis

Odor compounds from lemon, coffee beans, mint, and lavender were analyzed using GC-MS (Gas Chromatography-Mass Spectrometry). Headspace sampling was performed at room temperature via SPME (Solid-Phase Microextraction) with a DVB/CAR/PDMS (Divinylbenzene/Carboxen/Polydimethylsiloxane fiber (LabTech), followed by thermal desorption at 250°C for 3 minutes. The analysis used a DB-5MS column (Agilent, 30m × 0.25mm × 0.25μm) with helium as the carrier gas at 1 ml/minute. The temperature program started at 40°C (5 minutes), ramped to 150°C at 6°C/minute for 2 minute, and then to 280°C at 20°C/minute for 2 minute. The ion source and interface temperatures were 220°C and 280°C, respectively, with a scan range of m/z 29–500. Compounds were identified by comparing mass spectra with the Wiley 7.0 and NIST 2.0 databases.

4.3 Results and Discussion

This study recruited 12 participants (6 males and 6 females) aged between 22 and 49 years, with an average age of 31.2 years (standard deviation: 7.3). Regarding the question, “Do you regularly use perfumes or fragrance-related products?”, 2 participants reported frequent use, 9 reported occasional use, and 1 reported no use. For self-assessed olfactory sensitivity, 1 participant strongly agreed they were sensitive, 5 agreed, 4 were neutral, and 2 disagreed. Overall, most participants had experience using perfumes or fragrances, but their self-perception of olfactory sensitivity varied widely.

4.3.1Quantitative Results and Discussion

To minimize the impact of scoring habits, the study standardized the raw 1–7 ratings to a Z-score range of -1 to +1. The similarity and intensity results are shown in Figure 3. In terms of similarity, adsorbent material C demonstrated the highest consistency in performance, with Z-scores of 0.4, 0.8, 0.4, and 0.3 for mint, lemon, lavender, and coffee, respectively, highlighting its high fidelity across multiple odor types and its potential as a core material for versatile scent playback devices. For intensity, material F exhibited the strongest playback performance for mint (0.5), material C for lemon (1.0), material H for lavender (0.6), and material B for coffee (1.0). Collectively, material C demonstrated broad applicability for capturing and replaying diverse odors, with the highest similarity scores across all four odors and the best intensity score for lemon. Materials B, F, and H also showed superior performance for coffee, mint, and lavender intensity, respectively.

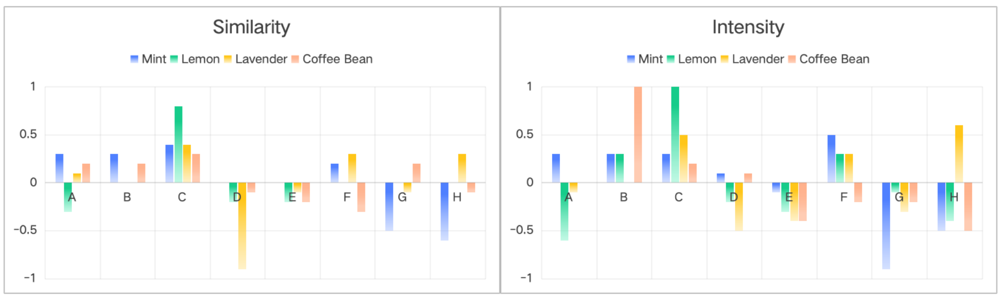

Figure 3: The Z-score of odor similarity (left) and intensity (right)

The correlation between standardized similarity and intensity ratings is shown in Figure 4, with a Pearson correlation coefficient of 0.805, indicating a strong positive linear relationship. This suggests that the perceived intensity of an odor significantly influences its similarity rating.

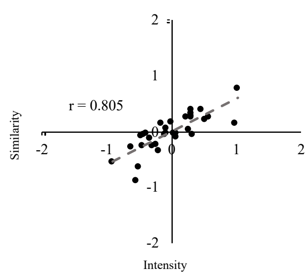

Figure 4: Correlation Between Standardized Scores of Odor Similarity and Intensity

4.3.2Quality result and Discussion

During the experiment, participants were asked whether they could evaluate odor similarity and intensity independently. The majority (7 participants) indicated they could not, noting that intensity significantly influenced similarity ratings. When intensity was too low, odor characteristics were perceived as weak, resulting in lower similarity scores. This finding aligns with the Pearson correlation coefficient (0.805), highlighting the critical role of intensity in similarity judgments. However, a subset of participants (5 individuals) believed that once odor intensity reached a certain threshold, similarity and intensity could be evaluated separately. This suggests that designing appropriate odor intensity is essential for enhancing user experiences with realistic scent playback.

Interestingly, when asked whether they could independently assess tone similarity and volume in auditory perception, most participants (8 individuals) responded affirmatively. This contrast indicates that olfactory perception may be more complex than auditory perception, influenced by factors such as the chemical composition of odors, individual sensitivity, and personal preferences.

Additionally, participants were also asked to explain whether their similarity ratings corresponded to their ability to identify specific odor categories. Results showed that at similarity scores of 3–4, participants could generally guess the odor category, such as associating mint with toothpaste or mint candy. At scores of 5–6, participants were able to identify specific odor sources, such as "fresh lemon leaves." Reviewing the raw similarity scores (see Appendix 2.2), certain adsorbent materials achieved similarity ratings of 4–5 or higher for different target odors. This demonstrates that the ScentEcho device, when paired with appropriate adsorbent materials, can effectively meet user expectations for high-fidelity odor playback.

In conclusion, the complexity of olfactory perception arises from its dependence on multiple factors, including the chemical properties of individual molecules and complex mixtures, as well as intensity and context. Additionally, the emotional and memory associations tied to odors suggest that personal experiences and situational factors may influence odor perception.

4.3.3Chemical Composition Analysis and Comparison with User Experiment Results

The chemical composition analysis (see Appendix 3) revealed that mint contained 10 compounds, primarily monoterpenes and sesquiterpenes (C10 and C15); lemon contained 14 compounds, dominated by monoterpenes (C10); lavender contained 18 compounds, including monoterpenes and oxygenated monoterpenes (C8–C15); and coffee beans contained over 20 compounds, mainly acids, pyrazines, and furans (C2–C10). These findings highlight the complexity and diversity of chemical compositions across different odors, which can directly influence the selection and performance of adsorbent materials.

However, the performance of adsorbent materials did not always align with the chemical composition of the odors. For example, although adsorbent material A (Tenax TA) is suitable for compounds with carbon numbers ranging from C7 to C26, it showed lower similarity and intensity scores for lemon (primarily C10) with Z-scores of -0.3 and -0.6, respectively. Similarly, adsorbent material C (Carbopack C), designed for compounds with carbon numbers between C12 and C20, achieved relatively high similarity scores for coffee (C2–C10), with a Z-score of 0.3. This discrepancy suggests that chemical composition does not always directly correlate with olfactory perception. Some highly abundant compounds may contribute little to odor perception, while others, such as pyridine (C_5H_5N) in coffee, which contains non-carbon elements, can significantly influence adsorption performance.While GC-MS provides objective insights into chemical composition, subjective olfactory perception remains a crucial factor in odor research. The design and selection of adsorbent materials should consider both chemical composition and actual olfactory performance to optimize odor collection and playback.

5 LIMITATION AND FUTURE WORK

While ScentEcho offers many advantages, its current design has some limitations. The air pump operates even when all self-locking switches are off, which may shorten its lifespan and compromise airtightness. To address this, we plan to optimize the circuit design to ensure the pump activates only when an air pathway is connected. Additionally, we aim to incorporate a heating function to enhance the variability of odor release intensity.

Additionally, to evaluate the effectiveness of adsorption materials across a wider range of odor sources, future experiments will explore adsorption performance for compounds with lower carbon numbers (e.g., C5) and higher carbon numbers (e.g., C20). A current limitation noted by participants is that the intensity of reproduced odors tends to be weaker than the original. Extending the adsorption time may enhance intensity, but it could also increase user waiting time, requiring careful balance. Some participants also reported detecting a metallic or rusty smell when testing faint odor samples, likely due to the material of the adsorption tubes. To mitigate this, we plan to experiment with alternative materials, such as fluoropolymers, to reduce unwanted interferences.

By simultaneously improving the hardware functionality and optimizing the adsorption materials, ScentEcho's range and depth of applications can be significantly expanded. Future work will also focus on exploring its integration into HCI scenarios to unlock its full potential in multisensory interaction design.

6 CONCLUSION

Olfaction is a key sensory modality for enhancing user experiences. This study developed ScentEcho, a portable device for odor collection and playback, featuring multi-odor storage, switching, and rapid playback functions. Systematic evaluation through user testing and GC-MS analysis revealed that Carbopack C achieved the highest similarity across all tested odors, while Tenax TA, Si gel-CN, and Carbopack B demonstrated superior playback intensity for mint, coffee, and lavender. The findings highlight the complexity of olfactory perception, where similarity and intensity are often interdependent, particularly at lower intensity levels, making it challenging for participants to clearly perceive odor characteristics. Additionally, chemical analysis showed that adsorption performance does not always align with chemical composition, underscoring the importance of combining objective methods with subjective perception. This study also addresses the current technical challenges of ScentEcho and explores its future potential, with plans to further optimize the prototype and expand its application scenarios.

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