Exploring Potential Scenarios and Design Implications Through A Camera-like Physical Odor Capture Prototype

Qi Lu[1,2,3], **Wan Liang**[1,2], **Hao Wu**[1,2], **Hoiian Wong**[1,2], **Haipeng Mi**[1,3], **Yingqing Xu**[1,2,3∗]
[1]Academy of Arts & Design, Tsinghua University, Beijing, China
[2]The Future Laboratory, Tsinghua University, Beijing, China
[3]Tsinghua University-Alibaba Joint Research Laboratory for Natural Interaction Experience, Tsinghua University, Beijing, China
{luq17, liang-w18, h-wu18, hkx18}@mails.tsinghua.edu.cn, haipeng.mi@acm.org, yqxu@tsinghua.edu.cn

ABSTRACT
Recently, researchers have become increasingly interested in finding new input methods for olfactory interfaces. Physical odor capture is a potential solution to this issue and, in order to make it more accessible for users, we designed a portable and fast smell capture prototype based on headspace technology and inspired by point-and-shoot cameras. We conducted a two-week diary study with 13 participants, in which they were allowed to freely use the prototype for odor capture activities. Through diary and interview feedback, we summarized factors such as the motivations of capturing, the collected odor types, and perceptual effects of odor replay. We found that the capture activities can positively affect user emotions, memory, or perception. User preferences on device parameters were also gathered to guide further design iterations. Physical odor capture has many potential applications in daily-life and other implications resulting from the study have been proposed for further research.

Author Keywords
Odor Capture; Olfactory Interface; Physical Olfactory Input; Exploratory Study.

CCS Concepts
•**Human-centered computing** → **Interface design prototyping; Field studies;** *User studies;*

INTRODUCTION
Many modalities have not yet been incorporated into current recording mediums other than vision and audition information, which hinders enhancement of user experience in multisensory interactions. Among those modalities, olfactory information deserves additional attention for its importance in evoking emotions and memories [25, 53], which matters to people's daily life.

The amount of research related to olfactory interfaces has been growing in recent years in the HCI community [43]. While most work have been focused on scent-enhanced applications [30], various odor display techniques [3, 23, 49, 55] are utilized to support applications such as message notifications [16, 37], social interaction [11], influence mood and perception [1], multimedia [39], multisensorial VR [42] and so on. They usually utilize predefined odor sources that dramatically limits their interactive space but reveals innovation opportunities of input techniques. The chemical not spectral nature of smell decides the different capture acts from light and sound [26]. Recording olfactory information can be divided into two phases – digital and physical. The digital phase involves acquiring digital representative data of various odors through analytic equipment such as electronic noses, gas chromatography-mass spectrometer (GC/MS), etc. Though some researchers were working on artificial noses as input methods of olfactory interfaces [12, 27, 28], the data do not completely represent a specific odor, that is, it cannot be used to reproduce the odor.

On the other hand, the technology of physical odor capture is commonly used in the chemical industry. Physical odor capture can be defined as extracting odorous compounds from the source substance or its volatiles, and the representative reference is the extraction of essential oils, which could be formulated into perfumes. For now, few works have looked into connecting physical smell capture with olfactory interface design. Moreover, due to their size, complexity and vulnerability, the current equipment used in industry or laboratories cannot be directly applied to construct an olfactory input device. Hence, the interface design and application scenarios are both under-explored areas.

In this paper, we first conducted a pilot interview to get inspirations for the design of a prototype for an odor capturing device. In order to make it simple and fast for ordinary users to collect real odors, we designed a "smell camera," which functions similarly to a point-and-shoot camera. A series of design parameters were proposed as criteria to evaluate the performance of the devices. Based on the design, a concept prototype was built by utilizing headspace technology [4] – a

∗indicates the corresponding author.

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universal method for gas sampling. We conducted a two-week diary study with 13 participants who were allowed to use the prototypes for smell capture activities freely. This real-world exploration of user action and motivation is the focus of this paper, which aims to give a context probing for later research in this area. In the results, we first summarized the motivations behind the choice of scent to collect, the odor types that users were most interested in, and the perceptual effects of odor playback. The findings reveal that the capture activities can positively affect user emotions, memory and perception. After interacting with the prototype, participants gave plentiful feedback about their preferences on device parameters, which were then used to guide further design iterations. It also indicates that there are rich opportunities and potential usages for portable smell capture in HCI research, even with limited technical performance. The challenges, limitations, and future work are also discussed.

The main contributions of this paper are: (1) the design of a point-and-shoot experience for physical odor capture processes and the development of a portable prototype supporting fast and simple collection of real odors, allowing for real-world exploration of smell capture activities. (2) The results from the diary study and follow-up interviews were summarized. User motivations, the overall effects of odor replay, feedback, and suggestions were gathered in the findings. (3) Potential applications, further opportunities, and discussions based on the study results, which could be referenced for future research in this area, were also concluded.

RELATED WORK

Olfactory Interfaces and Related Applications

Ever since Kaye encouraged the HCI community to use aromatic outputs in interface designs [30], abundant work focusing on smell-enhanced applications were done. For example, a variety of research showed that computer-generated smells could enhance experience and immersion in multimedia [20, 39]. Also, smell primaries can be bound with different symbolic information and utilized in message notifications [16, 37]. For a further step in providing immersive user experiences, smell modality has been utilized in cooking game design [41], augmenting gustatory sensation in VR [42] and rendering the virtual environment [45, 36]. For the above applications, one of the most significant drawbacks is the lack of odor primaries. They usually use limited odor sources to represent messages or render virtual environments, restricting on their interactive space and the complexity of expressed information. This is where physical odor collection can contribute. Users can collect odor sources on their own to interact with odors in daily life.

For social interaction, Choi et al. presented the Sound Perfume system allowing each friend bound to a fragrance ID to impress others more with the corresponding fragrance during face to face interaction [11]. The immediate odor capture can also elicit multi ways of social interactions between different subjects. Related findings are shown in our user study.

Brewster et al. [7] developed an olfactory photo browsing and search tool called Olfoto, which took advantage of the link between smell and memory [8]. Users could search and recall the photo with the tagged scents, smell cubes. However, they still used unrealistic prepared odors, so users had to construct the correspondence constrained. Combine photos with the actual scents of the objects depicted will be more useful to users. Alternatively, Obrist et al. [43] collected ample smell experiences and the accompanying memories and emotions. They also found that users "were wishing to capture pleasant smells, for instance from their childhood, and released to them in the present..." This showed that odors from past events are crucial to eliciting people's memories and emotions [25]. By collecting the immediate odors in the scenes, our prototype could help users record these important memory cues and evoke emotional feedback when playing back the scents.

Olfactory Input and Odor Capture Technologies

Traditionally, electronic noses and gas sensing are considered the main olfactory input technologies for accessibility, portability and endurance of environment monitoring. Additionally, research in ubiquitous computing adopted them for the ability to sense user activities unobtrusively. For example, gas sensing systems have been designed and implemented for indoor air quality analytics [19, 33], and Amores et al. [2] proposed a simple e-nose consisting of five gas sensors to detect bad odors of trash bins. Besides, gas sensors and e-noses are also used to detect cooking states [27, 32]. Moreover, Hirano et al. [28] presented a general smell sensing system uSmell, and they evaluated its essential efficacy and effect of airflow and distance on classification accuracy to provide a valuable reference for practical use. On a larger scale, e-noses were also applied to automatic urban smell map generation [21]. Those studies mostly converted odors into digital data, built statistical models to conduct odor recognition.

On the other hand, several researchers have worked on odor imitation and remote communication and utilized e-noses as "sniffers" [31]. Nakamoto et al. [40] proposed an overview of odor recorders and Teleolfaction [13]. Carmel et al. [9] presented a mix-to-mimic algorithm to mix an imitative odor instructed by a remote e-nose. Overall, generating odors by imitation required vast training, while the number is usually limited. In contrast, capturing odors physically is more practical to enable odor playback, storage, and sharing activities in instant and close-range scenarios.

For smell capture applications, Radcliffe et al. presented Scentography, an odor capture device utilizing headspace technology to obtain the smell of objects. However, their scent capsules were designed for chemical analysis and a specialist's (perfumer's) help was needed to reproduce the odors [51]. Odor capture technology is also used in heritage conservation. Bembibre et al. used solid-phase microextraction (SPME) [48] to capture the scents of old books [5], which took a long time to collect precise results.

DESIGN EXPLORATION

Since we aim to explore the potential scenarios and design implications for physical odor capture, we first designed a preliminary prototype to provide an opportunity for real-world studies. In this section, we summarized our design exploration process. First we conducted a pilot interview with 10 potential users in order to motivate the design. Then we designed the "smell camera" based on the operations of point-and-shoot cameras. The basic structure of the device, as well as important attributes and parameters were proposed. And a prototype implementation was placed at the end.

Pilot Interview

We conducted a pilot interview inspired by previous exploratory research [43] to probe the design directions of physical odor capture before constructing the design space. Ten participants with various occupations and ages from 20 to 29 (M = 25.2, SD = 2.6) were recruited to ensure diversity. These included undergraduate students, designers, HCI researchers, a programmer, an intern doctor, an entrepreneur and a junior high teacher. Interview questions were about their odor-related interests and memories, what they would record, why they replayed them and what the device should look like. Then we structured the transcribed interviews into scenarios, meanings and design inspirations through theme induction. The results were summarized: 1. Nearly all of the participants (n = 9) shared odor-related experiences. 2. Most of them expressed motivations like favorite smells and memorable scenes, whereas specific details about the scenarios were poor. 3. Two participants mentioning Polaroid Camera inspired the design factor of immediate odor acquisition.

However, the scenarios were not well revealed through interviews. Odor capture experiences were hard to describe without actual use of olfactory interfaces. Also, the odor-related experiences people actively recalled, called explicit olfactory memories [54], could not cover unconscious memories that are often cued by things other than verbal communication. Therefore, we designed and developed an odor capture prototype and conducted a real-world exploration using the prototype in order to explore further grounded scenarios and implications.

Design a Point-and-shoot "Smell Camera"

Inspired by a Polaroid camera, we took the methodology of metaphoric design in creating the odor capture device, since sharing similar interface features with existing recording mediums (cameras, audio recorders) will create intuitive interactions for users. The interface design trend of recording mediums has been enhancing accessibility for users, with an exception being equipment used by professionals. The metaphor we adopted is the point-and-shoot camera, a classic example for designing recording mediums. We first summarized the common components of a recording medium from the perspective of functional abstraction. The basic components are listed below. Additionally, we shaped the "smell camera" referring to the composition of point-and-shoot cameras (See Table1).

User controls. The design of the user control panel, a central interactive part may include the operational mode, position, size, and identifiers. As most users have been familiar with the point-and-shoot experience, the control panel of the scent camera can be designed to mimic a camera or camcorder.

Information entry. Nearly every recording device has a "collector" to gather the specific type of information. The camera refers to the lens. The sound recorder refers to the microphone.

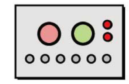
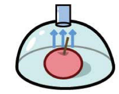
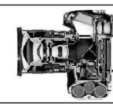
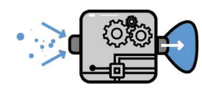
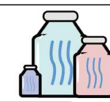
Function	Camera	Smell Camera
User Controls		
Information Entry		
Core Capture Unit		
Storage Unit		

Table 1. The corresponding components of a camera and an odor capture device. For the latter, abstract sketches were used to represent each component, and does not represent the specific design implementations.

Accordingly, a portion responsible for gathering odorants (olfactory information) is required for the smell camera.

Core capture unit. Each recording device has a main body that contains its core technical components. The capture unit of a camera is the image sensor, which can convert light on the lens into digital signals. For olfactory information collection, the most reasonable correspondence to image sensors are gas sensors. They convert chemical odorants into electrical signals, but for physical odor capture, extraction techniques in the chemical field should be given more attention in the design.

Storage unit. Traditional cameras used analog film as the storage unit and digital cameras started to apply digital memory techniques. Similarly, storing physical odors is an issue of chemical storage. However, to create a camera-like capture device, the storage unit should also provide safe and fast odorant access (input and output).

Design Parameters of the Device

For performance evaluation of the odor capture device, we concluded five design parameters to represent the different dimensions of the design. The design is evaluated from three aspects: *a) immediate odor acquisition results from pilot interviews, b) analysis of the characteristics of recording devices with similar basic components, c) investigation of techniques related to odor collection [4, 18, 29, 46]*. These parameters constructed user feedback outlines for the design iteration. Moreover, parameter weights of different scenarios are worth discussing further.

Fidelity. Just as the resolutions of video recording develop better, the quality of the collected odors should also be considered. Odor fidelity is the degree of similarity between the playback odor and the original user collected odor. Many factors will affect odor fidelity, including the proportion of volatile scent components being collected, the contamination of the sample during the collection process, the denaturing activities in the storage medium, delivery controls during odor playback, and so on.

The time cost of the capture process is another key factor influencing users' willingness to use the device. The capture process taking hours or days would not be suitable for most interactive applications. Not only may users quit collecting, but scents may vary. Additionally, a collection method requiring a longer duration may distort results due to other scents mixing over time. Our goal is to reduce capture time as short as possible and to further potentially record changes of captured olfactory "frames" to create "scent videos".

Storability. Physical smell storage cannot be permanently stored like images or sounds. The storage ability involves two aspects: capacity and duration. The storage capacity indicates how many odorants can be stored per unit volume of the storage medium, and the storage duration refers to how long the storage medium can prevent the odorant from leaking or deteriorating. Hence, the storability of a smell camera largely determines its scenario scope.

The appearance of the device strongly affects users' willingness to use. It relates to design factors such as size, shape, ergonomics, etc. Furthermore, it is limited by the techniques used to construct the aforementioned basic components.

Interaction method. As a point-and-shoot experience, the interaction method should be simple and intuitive. Besides the collection of information, the preparation and the detaching process of the storage units should also be considered.

Prototype Implementation

After filtering relevant technologies, we adopted the method of *dynamic headspace sampling* [4], a branch of headspace technology, to build a concept prototype based on the above design exploration. We chose this method for its shorter time-consumption and better portability to create a camera-like shooting experience, compared to those essential oil extraction techniques [18, 46]. It uses a vacuum pump to collect odorous air, and the odorants are then sampled directly by gas sampling bags. And we tried to simplify the interaction process of the device to improve affordability.

The hardware overview is shown in Fig 1 a, which includes the main control module, headspace cover (***information entry***), remote controller, and some additional accessories. The main control module (***core capture unit***, Fig 1 b) consists of a vacuum pump(12V, 15L/min), a microcontroller (ATmega32U4, 3.3V, 8Mhz) [47] and a PWM driver board. A 12.6V, 3000mAh Li-Po battery is used to power the entire system, and an extra LDO(AMS1117-3.3V) is mounted to regulate voltage for powering the control board. We designed the internal structure of the prototype to minimize the size while maintaining good endurance and capture efficiency. The scented-air channels adopt Teflon tubes to prevent contamination. The casing was 3d-printed using PLA filaments. We selected an Aluminium-foil composite multi-layer film gas sampling bag(1L) [24] to sample the scented air. The bag is chemically inert, impermeable and has low adsorption (***storage unit***), and its small capacity also helps reduce health and

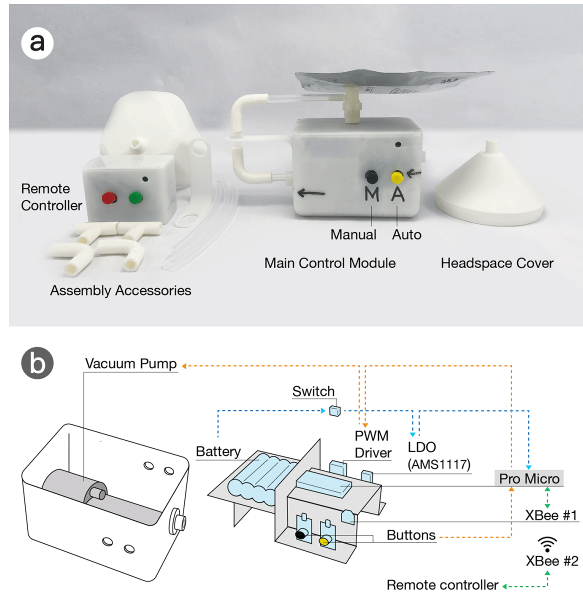


Figure 1. a) A hardware overview of the prototype. b) The internal structure of the main control module.

safety risks, because the number of toxic molecules and bacteria that may be inhaled is deficient.

User controls: Two control buttons are on the front of the box: pressing the yellow one could stop the extraction automatically (*Timecost: 4s*, "Auto" mode). The other allows multiple presses to adjust extraction speed and to stop extraction manually (*Timecost: low-speed ~12s, high speed ~4s*, "Manual" mode). We built a remote controller with the same control scheme for situations where it is not convenient to control the device directly. For wireless communication, we used the wireless protocol of the Zigbee V2(Module: XBee S2C [14]).

The interaction method for the prototype is shown in the Fig 2. Before use, a simple installation to connect the storage bag and the headspace cover onto the main module is needed. The user can then select one of the collection modes, press the button, and collect the odor. After collection, the user needs to turn off the valve and pull out the bag. For playback, the most common method is to turn on the valve of the sampling bag and to directly press it to let the scented air out from its nozzle. The other method is to use the main control module to siphon the air out, which enables a stable delivery and speed control(Automatic type, channels assembly needed).

EXPLORATORY DIARY STUDY

We conducted a diary study and a post-hoc interview investigating the following research questions: **1)** *What motivates users to capture odors?* **2)** *How do they interact with the prototype and the captured scents?* **3)** *What odors users will capture?* **4)** *What values can the new olfactory interaction contribute to?* **5)** *What is the user preference on the design parameters of the odor capture device?* We also expect to explore more grounded user scenarios and more thorough de-

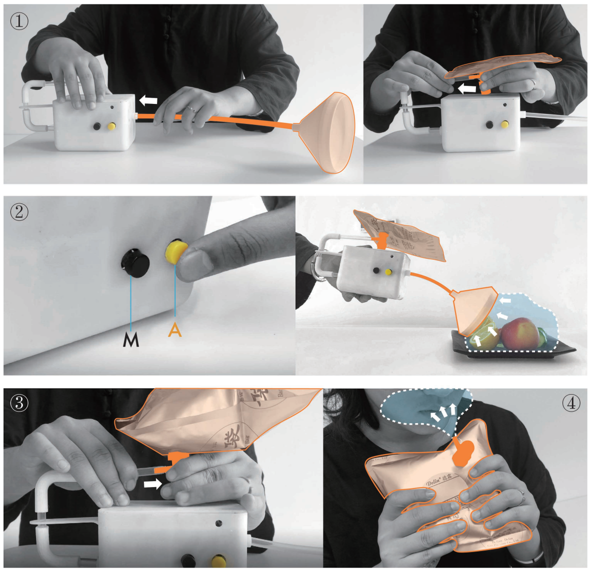


Figure 2. The typical interactive process of this prototype: 1) Simple installation. 2) Press any button to start collecting. 3) Detach the bag and turn off the valve to store the air. 4) Playback: turn on the valve and press on the bag.

sign implications for further iterations through users’ feedback about the experience.

Participants

We recruited 13 adults (7 females), aged 18 to 57 (M = 27.92, SD = 9.76). All of them have a healthy olfactory function, no history of odor allergy, and expressed enthusiasm for recording or sharing their life and exploring our odor device, thus meeting our selection criteria. Participants were told about the purposes of the study before they join in.

Preparation

The non-filtered smell capture and possible deterioration after long-term storage required specific protective measures and to inform participants of potential risks. Before delivery to the participants, we disinfected and ventilated the device to ensure that it was odorless and hygienic. Six clean sampling bags and adequate replaceable accessories were provided. Then we conducted a training program for every participant, which included the interaction method and some precautions: **1)** *If people feel the smell has deteriorated, they should stop reviewing immediately and no longer use the bag.* **2)** *They should collect daily life odors instead of toxic and dangerous gases.* **3)** *The device should be ventilated regularly (keep the pump running in the air circulation) to retain clean.* Written informed consent was obtained after the training.

Diaries

To lower the burden of diary studies under mobile conditions, we adopted the snippet technique, which allowed participants to capture snippets of text, audio, or pictures on-site in a few seconds [6], and allowed them to complete the thorough, structured diary entries later. Besides basic information including date, site and the event, people logged responses regarding their motivations, feelings, and details during the experience via short descriptions or sentence completions. For instance: *"What is the smell you want to collect? How do you realize that this smell exists?"* An example of intention exploration through sentence completion is *"If you do not review this smell after the collection, you intend to use it for. . . "* This format garners responses with minimal guidance necessary. Participants kept the diary for about two weeks and were required to have at minimum 4 logs – 2 capture experience logs and 2 playback experience logs, but were encouraged to experience the process of capturing scents and playing back the scents.

Interviews

After handing in all the diaries and finishing their experiences, a semi-structured interview was held to aid in the interpretation of the diary. The interviews were held in person or remotely and lasted up to one hour. The semi-structured interviews elaborated on diary entries and questions such as what motivated them to record the odors, what induced the feelings, in what ways do the events play a role, and how they perceived the odors and the differences from the photos. Odor reminiscences were discussed, as well as possible scenarios and applications for the device.

Analysis

Diary entries and transcribed interviews were analyzed using a qualitative thematic analysis that aimed for data reduction and the identification of recurring themes through inductive coding of the data by two coders. Entries were coded twice: first, all entries were broken down into a single strip conveying one information called a code. Secondly, entries were clustered based on emergent affinities and our preset dimensions, such as motivations. Some inspired insights were discussed as well.

FINDINGS

Here we provide summaries about the findings from our exploratory study including motivations, sensory experience, effects on memory and perception, and user feedback on design parameters. The quotes are mostly from the interview and those from the diary are marked with “(D)”.

What Motivated Them to Record the Odor?

Recording the Enjoyable Odors

Most participants collected the odors in order to repeat sensory stimulation, among which food was the dominant type of odor. The pleasure induced by food odors strongly influenced their behaviors in capturing and preserving scents. P4 collected hotpot odors while having dinner with her friends in a restaurant. The device excited her because she always wanted to record the odors of her favorite foods. She expressed her desire to record the food: *“Every time I enjoyed a hearty meal with friends, I always considered why I could not take the tasty smell home so I can smell it when I am hungry or greedy.”* Besides food, perfume as a personal identity also brought participants pleasure. P7 shared the experience of his perfume capturing motivation: *“When I passed by a girl with charming fragrance, I was wondering how fantastic it would be if I could preserve her scent.”*

Recording these odors also strengthened people's feelings towards the objects. Food as a cue can prompt memories of social gatherings, past events, people's preferences, and relationships with family members [50]. Food has a strong connection with olfaction and is a prevalent object type that people might often want to record. P1 was attracted by the noodle his wife was eating and collected the odor, *"the noodle my wife ate smelled tasty and recording the odor could help me remember the special food and odors better."* They collected the pleasant odors to create a magnified, vivid and immersive feeling, which also strengthened the scenario impression. P13 described once coming across a girl with specific perfume:*"I cannot describe the perfume scent of the girl passing by just now. But I can surely identify it next time I smell it. It would remind me that it was someday and somewhere I met her. Without capturing scents I may forget such a thing."*

Retaining Meaningful Feelings and Memorable Events

Besides sensory enjoyment, odors could become symbols representing events or feelings, thus eliciting the participants' impulse to retain them. P3 wrote that *"I felt good when I was drying my clothes and smelling the laundry detergent. The pleasant odor for me meant sunshine and happiness as if everything was clean... the scent photo should be taken beautifully and properly to retain the feeling of happiness this odor brought me."*(D) This suggested that odors can be a stronger tunnel to convey feelings under some circumstances. People connected the odors with some inner feelings and metaphors. Collecting the symbolic odors built bridges to fleeting moments and faint feelings.

In a memorable event, the odor could remind people of subtle feelings and easily overlooked details. That was why P13 wanted to capture memory-related odors: *"I collected them not because of the fragrance. I would choose the odors related to specific memories. All these three had the characteristic of relating to memorable events. The third odor was from the cover of my notebook. It was a gift from someone in a beautiful festival. The strong odor impressed me, so I collected it. The person and the memory had special meaning to me."* Such memorable events may only happen once in our life, which made recording it meaningful. P1 recorded the odors of his newborn daughter to retain her scent. The odor of his daughter represented purity to him. He collected the odors of his daughter as a medium to remember her growth: *"I want my daughter to experience her time as a baby in the way of scents in addition to photos when she grows up."*

Sharing the Odors

People also recorded the odors to share with others, including convincing others of their feelings, recommending food, playing tricks on people or pets, and providing a new problem-solving method.

Sharing with Families or Friends. Odors shared with others can conform to the feelings and appraisals of the same objects. Odor-induced moods and perceptions are difficult to describe in words or pictures. Obrist et al. revealed the smell technology could be used to share odors with families and friends [44], our findings supported this idea and gave more instances. For example, P10 collected the scents of noodles to share with her roommate: *"I often eat snails rice noodles with one roommate, which is a leisure activity. But another roommate is scared of that odor. That day I ordered the food and collected the odor to play a trick on her. I let her experience the happiness we felt while eating the food."* P4 often had dinner with her friends, and she wanted to share the food odors. *"I will share it with my friends to recommend the delicious food."* P12 also expressed her motivation for sharing. The sharing of odors allowed her to show off when her friends experience the same odor.

Sharing with Strangers. People also shared odors with strangers to show them how odor collecting works. P2 collected the coffee fragrance in the cafe, and she described how others changed attitudes towards the device after smelling the collected odor:*"At first the coffee maker doubted whether the device could capture coffee fragrance. After I presented the collected coffee scent, they found the smell amazingly strong and were joking that I stole the soul of the coffee."* Another compelling purpose was to use odors as a diagnostic tool. P7 shared the odors with strangers for the exclusive purpose of curing his cat. He wondered whether the odor of cat feces could be a diagnostic material. He collected his cat feces when his cat was ill, and he thought that *"the odor of cat feces could help the vet diagnose the cat."*

Being Curious about the Performance of Smell Capture

Some odors were collected out of curiosity. With a device that recorded odors, people might tend to focus on habitual spots and explore their life more actively. P4 unintentionally burnt the frying egg and evoked her impulse of collecting the odor: *"The egg was burnt and I was curious about how the collected odor smelled. Would it smell different from the burnt egg itself?"* P3 was curious about the smell of the steam during showers and noted in the diary that *"I felt the strong smell of steam when going to the bathroom and I wondered whether this kind of smell could be recorded."*(D) The device satisfies the motivations of people who had a curiosity of unknown odors.

Sensory Experience of Odor Playback

Participants collected a total of 57 odors ($M = 4.38$, $SD = 2.06$). We categorized these odors into 5 types: food, artificial odors (e.g., perfume, detergent), body-related odors (e.g., scents of a baby, clothes), ambient odors and odorless odors with ritual or memorable value(e.g., the smell of hometown). To evaluate the odor replay effects compared with the original scents, we categorized 6 types: same, faded, changed, none, odorless originally, and not-reviewed. Odor reviewing effects of different odor types were shown in Fig 3 a. Most odors participants collected were food and artificial odors. Most odors maintained the same or faded, and a few changed or smelled odorless. Surprisingly, some participants collected odorless scents bringing them ritual feelings, such as the scent of the air during parent-child collaboration/play. A few odors were not reviewed such as the cat feces, since it was for teasing the cat.

We also categorized the duration between collecting and reviewing odors into 5 periods: less than 1 hour, less than 1 day, 1 - 2 days, 3 - 5 days, 6 days or more. We reported

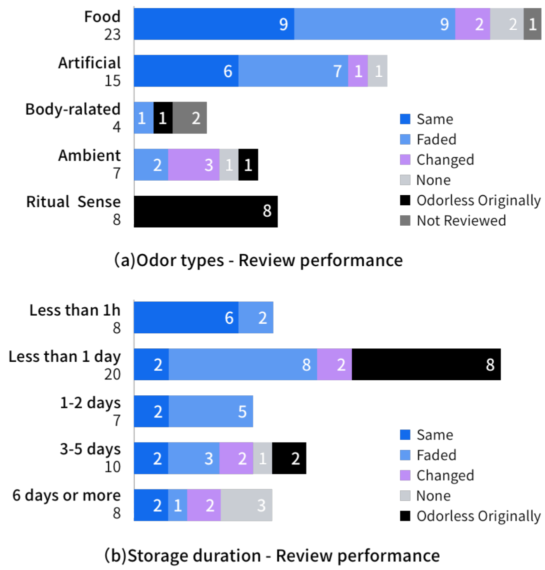


Figure 3. The basic capture performance of the prototype, all reviews were scored in comparison with the original odors.

the odor reviewing effects of different durations between collecting and reviewing odors in Fig 3 b. There was a trend in the preservation ability of the odors as they were declining through time.

Effects on Memory and Perception

As a new type of olfactory interaction, scent capture can help people memorize their life and feelings. Further, the new prototype allows new behaviors and perception to happen coincidentally. In comparison with sensory experiences, subjective feedback is more meaningful for new scenario explorations. According to the analysis, we summarized the subjective effects on memory and perception.

Enhancing Memory and Emotion

Many relevant studies have confirmed odors can enhance human memory and emotion [8, 44, 53]. Seven participants (P1, P2, P3, P4, P6, P11, P13) reported that the playback of odors enhanced their memory of scenes and events and brought them greater emotional arousal. P1 reflected on the effect credited to the new sensory stimulation (stored odors): *"Though odors faded, they were still similar to the ones which elicited my emotions at the time. Compared with photos or pure imagination, this provided a new sensory stimulation that did not exist before, thus helping me activate my emotions and memories of the scene more. "* Some odor-related scenarios had a more reliable connection with emotions beyond events. P13 collected the odor of a notebook, which was a gift from a special friend: *"The odor replay made me re-experience emotions first instead of events. I could not take photos of the moment he gave me the gift. When I smelled the odor, the scene came out vividly in a way I might not realize or recall before. The emotion for me is mixed and complicated."* This indicates that olfactory information can play a unique role in cuing memories and is more emotion-related than visual information.

Attaining New Perception

The collected odors can provide a channel to attain new perceptions beyond usual expectations. Due to some places being hard to reach for our noses, the device can help collect unexpected odors. P1 and P6 reported that they attained new perceptions during their capture and replay experience. For example, P6's target odor was from a flower. *"The flower was too small, so I did not smell the obvious smell at that time. What I smelled was like the whole grassland, and it was fresh."* She had put the tube end close to the flower when collecting. Then she got a different smell, *"It felt a bit novel, I had not expected to smell the flower's scent again. It was somehow different from what I perceived that day, but closer to the essence of a flower... very satisfied and quite unexpected... It can capture the smell that the nose can not capture."* The device as an olfaction extension may offer new sensory experiences which possibly could bring new perception.

User Feedback on Design Parameters

Appearance and Interaction

Regarding the appearance and interaction of the device, some participants thought that the device was not portable enough to meet all the capture scenarios they wanted. Thus, they provided suggestions on how to polish the design to provide a better scent capture experience.

P10 was reluctant to capture the scent outside due to the inconvenience of the operation: *"Now it is necessary to install the accessories, which is inconvenient to operate. It feels a bit exaggerated and noisy to hold it, so I will be embarrassed to take it out. Therefore, if the operation is more convenient in the future, I will use it more outdoors."* P9 felt troublesome carrying so many accessories out:*"Carrying the tube is a bit cumbersome, and the inflated bags take up space, which is very inconvenient."* These imply that we can integrate all the parts to lower the inconvenience before and during the interaction.

The appearance is another block of taking the device out. *"The size is a bit large, and the cube is not suitable for carrying. It can be made flat (like an iPad) or reduced overall." (P1) "The size can be designed like a digital camera, not a monocular camera. About 10cm $\times$ 8cm, or 12cm $\times$ 8cm length by width, and 5cm thick, similar to a power bank." (P13)*

Moreover, some users would like to try new usage scenarios if the device became more portable and simplified. P1 wanted to collect the scent of the maternity ward:*"I wanted to collect the unique scent of the maternity ward. But I was too busy to take a lot of things. Besides, the device required certain operations, such as installing bags and tubes."*

Fidelity and Storability

According to the occupations of different participants and the purposes of scent replaying, they expressed different demands on the fidelity and storability of the captured smells. We found that trade-offs existed between the two parameters. For example, P11 was a barista who was very sensitive to the smell, thus he considered fidelity as the most important. He claimed that if the scent had no excellent performance in terms of fidelity, the storability would be meaningless: *"The captured scents are like photos. An obscure photo that has been stored for 100 years is still of no value to me."* Moreover, he hoped that the smell could be strengthened based on the original, which exceeded the design expectations for the fidelity parameter: *"The smell I want to collect is not so strong, so I want to make it more condensed and discernible. "*(P11)

Demands differ on the storage duration for various collection purposes. P1 wanted to capture the smell of the newborn and replay it when his child grew up. which requires at least decades of storage. In contrast, many participants shared the odors in a few days, which only requires short-term storage.

Besides, some participants were not satisfied with the storage capacity since the scent in the gas sampling bag was challenging to replay repeatedly. As P5 mentioned, *"I hope I can replay the smell repeatedly, just like the photos can be seen repeatedly in the album."* Thus, the design of the storage unit could be separated into multiple cells to help control the volume of a single replay. P10 shared her idea about the capacity design of the storage: *"On my first experience, I could smell the odor by squeezing the bag. I thought it was amazing and then shared it with my roommate. But the amount left was not enough for her to smell. I think you can develop a storage package containing multiple cells. This will enable users to squeeze one cell at a time to increase the usage frequency."*

Timecost of the Capture Process

The time cost of the capture process (Auto mode: 4s) was accepted by most participants. Nevertheless, the preference of the capture process duration was influenced by the collection results, the operation of the device, and the capturing scenarios. Firstly, some participants suggested that they were willing to spend a longer time in exchange for a better scent collection result (better performance in fidelity and storability). The most mentioned time is about 1 - 2 minutes. *"I think it should be about one minute, but if the collection performance is particularly good, it can be two or three minutes."(P4)* Furthermore, P1 would accept even 5 - 6 minutes: *"5 - 6min is acceptable. More than 10min is not acceptable unless the smell to be collected is very important and special."*

Alternatively, for some cases in which the device could be placed independently without holding, users would accept an even longer capture time. *"I think 10 minutes is fine for me, I can put the device there and do my own things. Even for other scenarios, like having a meal for 2 hours and capturing at the same time is also reasonable."* On the other hand, P9 would like to capture the smell faster while traveling. Thus she thought that the timecost should be as short as possible. To summarize, it indicates that the acceptable timecost differs according to how users behave in different scenarios.

Potential Applications

Here we conclude some potential applications inspired by the participants' diaries and interviews. Such applications could provide further directions for olfactory interface research.

Face-to-face Social Interaction

The Internet allows for boundless information transfers, whereas it reduces the frequency of face-to-face social interactions. Scent sharing can improve face-to-face communication. The physical characteristic of odors determines the close connection among people when they share them. Odor-evoked behaviors can strengthen people's face-to-face bonding interactions [10], and odor capture provides a new way to interact with others. We found the following social behaviors associated with the capture experiences: **1) Sharing emotions**: P10 said *"I collected the smell so she could feel our happiness and relaxation when she came back."* **2) Conducting practical jokes**: P8 used unpleasant odors (such as those from her cat's feces) to play practical jokes on her friends. **3) Using the device as a shared activity**: P6 said *"My daughter and her friends played games by using the device."* In conclusion, the capture activities extended the motivations and behaviors of face-to-face social interactions.

Storytelling and Child Education

As the device allows fast and unrestricted odor capture, P2 shared her idea of using it as a composition tool for use in storytelling: *"The collected odors can be combined with storytelling. For example, I can collect a stink in advance, and use it to represent Wolf's bad breath while I am telling the story of the* ***Little Red Riding Hood****. It makes the context more interesting and vivid."* A similar idea has been proposed in prior study [44], but we rediscovered it from diverse angles. The emergence of new olfactory experiences may enhance the listening experience and improve the effectiveness of child education. Parents can not only educate their children via storytelling but also allow them to use the device and to create stories themselves in a creative manner. As P6 said: *"I told my daughter a story while she was smelling the odors to let her imagine the scene according to the smell, or I would ask her to smell the odors she collected, and let her recall and paraphrase what had happened."* P6 thought that such exercises improved the children's memory and imagination. Additionally, the new experiences induced by different scents can also strengthen parent-child connections and train children's expressive skills.

Scent "Photography"

Some participants' experience indicated that odor capture has a potential for artistic and self-expression usages: P11 collected the smell of incense in the hopes that he could record the subjective feeling of how it related to his life, not only the odor itself. Odor collection can become an art fashion to express subjective emotions and consciousness, just like painting or photography, and it could assist olfactory artists during their artistic creation process[34].

Besides, many participants hoped to learn the "shooting skills of smell photos," such as using the headspace cover to increase the concentration before collecting to improve the capture performance. P8 expressed his confusion about the operation: *"I think I need some technical training in collecting odors just like I need some skills to shoot good photos."* It is easy to collect odors using the prototype, but the methods of collecting high-fidelity odors still needs to be explored.

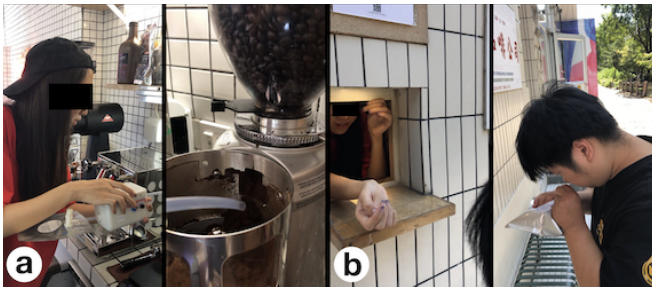


Figure 4. a) Using the prototype to capture the smell of coffee powder. b) Giving a scent gift to a passerby. (Photos provided by P2)

Instant Olfactory Advertisement

Immediate scent capture can provide a method of advertising for shops selling merchandise with attractive scents. Odors have been used pervasively in scent marketing [17]. For example, the scent of bread is the best advertisement for bakeries. P2 collected the scent of ground coffee and shared the scent with a passerby (Fig 4), receiving positive customer feedback and making the coffee shop owner want to use this prototype for advertisement. These instant capture and replay experiences allow customers to know and feel the process of food preparation. Thus, customers can become more familiar with the food preparation process through the replay of scents, such as the smell of fresh ingredients. The use of scent can be an immersive experience for the customer.

Unreachable Spots

Chemically, the transmission distance of scents is limited depending on its volatile amount and time cost. Moreover, the scents need to spread through the air and into the nasal cavity, which means that people can only smell the scents around their nose. As the capture experience shared by P6 (in *Findings: Attaining New Perception*) showed, people can capture the scents of objects that may be out of the range of human noses.

Odor identification Training

Former research like Maggioni et al. [37] have shown that training of scent-associations can improve users' performance in scent identification tasks. In contrast, our interview revealed that instant odor collection could be utilized for some more professional scent training purposes. P4 shared her story in which, as a sort of training, she had collected the odors of her cat's feces and made the cat inhale the odorous gases whenever it defecated outside the litter-box. The profession of P11, as a barista, made him want to collect different odor samples to train his students on how to identify them. Such scenarios inspired us that this prototype can provide convenient scent collection for odor training. Odor training is a necessary process of specific occupations such as coffee makers. Pets as odor sensitive animals can be trained to learn suitable behaviors. Instant capture and replay prototype can lower the cost and increase the convenience of training.

Suggestions on Multi-sensory Experience Design

As scent capture cannot meet all the needs about information input, we gained valuable feedback regarding the incorporation of the scent capture device with other technologies and recording modalities.

Incorporation with Visual and Audio Media.

P2 suggested that *"You can stick a photo on (the bag's) one side and on the other side provide some space where we can write some text, and we can just keep this to help memorize, or share with others. It will be much better since it will be giving more detail."* P5 and P7 expressed that they wanted to take videos while collecting the smell, e.g. P5: *"...It's good to add scents into wedding VCRs."* It has been proved that additional olfactory cues can enhance one's sense of presence and memory [15]. When people experience a memorable event, they expect to record details and to preserve their memory. Such scenarios provide designers the insight that multi-sensory recording can be used in many scenes, and further, it can also help create realistic MR content [22, 36].

In Combination with the Recording of Haptic Information.

We observed that olfactory perception was usually accompanied by haptic feelings such as temperature, humidity and airflow, whereas the prototype was not able to support collecting and replaying the haptic sensations. For example, P11 liked the smell of the refrigerator in the supermarket. When she reviewed the odor, *"The cold scented air coming into my nose was quite good. But I can't feel anything right now."* P3 captured some scents from steam when showering. Her review log indicated that: *"It doesn't smell like steam now..."*(D) These reflect a need for the capture of haptic information in order to build a better playback experience. However, there are difficulties regarding output – rendering the sensations together with odors. Since there has been some exploration regarding multi-sensory environment rendering in VR [45], we believe that the combination of olfactory and haptic experiences will be a promising research direction.

Single Olfactory Experiences.

However, this should be considered separately from scenarios that primarily focus on the enjoyment of smell. P2 wrote: *"I prefer experiencing pure smells. Binding them together destroys the aesthetics of the collected odors."*(D) This suggests that combining additional sensory information does not necessarily improve the experience. Though P8 suggested adding photo and text, he also expressed that *"I cannot focus on the smell with the interference of lighting and noise... Maybe you should design something special to help users focus on the smell."* As P10 mentioned, when she was eating the noodles, she wanted to involve herself in smelling the appetizing odor and had no willingness to take pictures. Since some collected odors were used to represent the whole enjoyable experience itself, adding new modalities such as taking a photo of the scenario is a burden on the experience. Thus, such odor immersive scenarios need designs for single sensory modality.

In summary, whether to combine other modalities or not depends on user needs. Recording more modalities could be considered when people want to record the whole event, while the focus should be on providing a better experience for the enjoyment of a single olfactory modality.

DISCUSSION

Ethical and Social Concerns

This new recording medium could elicit ethical concerns. Capture the scent of a stranger may cause sexual or romantic issues. For instance, P7 and P13 expressed their thoughts of capturing the scent of "a girl passing by." Such capturing behaviors possibly induce safety or relationship threats like sexual assault [38]. Besides, capturing odors from the non-public odor sources may occupy others' belongings and offend others. Similar problems happen in photography activities. Indeed, law restrictions and ethical norms are necessary to regulate development. More importantly, we should consider protective design from the beginning, which is similar to the mandatory shutter sound design of smartphone cameras to protect the privacy of others when taking pictures. Furthermore, many participants expressed that the study inspired them to observe their daily life from the "perspective of smell," new behaviors may happen accordingly. However, such new behaviors may elicit new ethical concerns. Thus, designers should have a sense of mission to take ethical issues into account when designing odor-related interactions. The new norms should be constructed through the development of technology and design thinking.

Sufficient Capture and Storage Technology

The direct gas sampling method is fast and straightforward to use and available to most VOCs. However, its main drawbacks are its limited storage space and odor concentration, since the extracted air dilutes the original odor concentration. Additionally, air may cause the odor to deteriorate, while improving storage conditions such as low temperature can slow down but not eliminate the problem. Therefore, more investigations are needed to explore solutions for better fidelity and storability. New technologies on scent extraction and new materials are the areas that are worthwhile to look into [46, 35]. On the other hand, a combination of multiple techniques may also be a good idea, since the different techniques can specialize in different odor types or usage scenarios. In this way, the device can provide different "modes" for users. For sustainable usage, some participants tried to re-use sampling bags. However, for odors with high strength or retention, it is hard to eliminate the odor remaining in the sampling bags effectively. Therefore it is necessary to develop corresponding recycling technologies for the storage units.

Health Safety for Scent Capture

As our prototype was developed preliminarily for the exploratory study, safety protection was not involved in the design. Nevertheless, we fully informed the participants about the precautions to protect their health. Also, the possibility of odor deterioration leading to health threats was very slight due to such a low amount and concentration of the collected odorants. However, health issues need to be taken into account in subsequent designs as we tend to improve the collected amount and concentration. Besides, some participants used the prototype to capture bad smells, which indicated to us the potential risk of device contamination. In addition to the new technology for capture and storage, other measures can also be adopted to preserve users' health, such as installing disinfection filters [52], optimizing the gas path, and designing self-cleaning modules.

LIMITATIONS AND FUTURE WORK

Precious findings and implications were harvested from the exploratory study. However, it should be noticed that some participants joined the study out of curiosity may skew the results. Although the minimum number of experiences is set up to four times (4 logs) to reduce this bias, the recruitment strategy should be improved in further study.

Though the prototype in this work provides the necessary functionalities to perform the exploratory study, some drawbacks still limit the depth and breadth of the investigation. Three participants (P2,7,9) felt embarrassed when capturing odors in public, while four participants (P10,11,12,13) stayed indoors due to the inconvenience of carrying it out. These negative attitudes stemming from the large device size might bias results and restrict possible scenarios. Though the structure design under the current technical scheme was optimal in terms of collection time cost and pump power, the user study revealed that we could switch to a smaller pump to reduce the overall size at the expense of capture efficiency. Moreover, gas sampling bags had been sufficient storage units for the exploratory study, but users reported that there would be certain cases that would require long-term scent storage. And the ethical and safety issues of scent capture and storage should also be considered carefully. Therefore, we will continue to explore better capture methods and storage mediums for physical odor capture in the future. Moreover, we will continue to iterate current prototypes based on suggestions gathered in the exploratory study, such as combining odor capture with other input modalities, improving the user experience of the whole interaction process, and optimizing for single odor domains.

Moreover, we found that professionals often dealing with odors may have more demanding application scenarios (such as *odor identification training*). Therefore future work could include detailed evaluations against a more critical user population (e.g., scent designers, sommeliers).

CONCLUSION

Smell is one of the essential experiences in our daily lives. In this paper, we combined physical odor capture with an olfactory interface to develop a research prototype "smell camera" that captures real odors while providing a point-and-shoot experience for the collection process. A two-week real-world exploratory study using the prototype showed that physical odor capture is useful and adds value to people's daily lives. We summarized applications and opportunities from user feedback for further research. Ethical and safety concerns and technical challenges were also discussed. While recognizing the existing limitations, we will continue to explore new technologies and to promote design iterations for odor capture.

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