inScent: a Wearable Olfactory Display as an Amplification for Mobile Notifications

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ABSTRACT
We introduce *inScent*, a wearable olfactory display that can be worn in mobile everyday situations and allows the user to receive personal scented notifications, i.e. *scentifications*. Olfaction, i.e. the sense of smell, is used by humans as a sensorial information channel as an element for experiencing the environment. Olfactory sensations are closely linked to emotions and memories, but also notify about personal dangers such as fire or foulness. We want to utilize the properties of smell as a notification channel by amplifying received mobile notifications with artificially emitted scents. We built a wearable olfactory display that can be worn as a pendant around the neck and contains up to eight different scent aromas that can be inserted and quickly exchanged via small scent cartridges. Upon emission, scent aroma is vaporized and blown towards the user. A hardware - and software framework is presented that allows developers to add scents to their mobile applications. In a qualitative user study, participants wore the *inScent* wearable in public. We used subsequent semi-structured interviews and grounded theory to build a common understanding of the experience and derived lessons learned for the use of *scentifications* in mobile situations.

Author Keywords
Olfaction; scent-based notification; wearable device; olfactory display

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
The sense of smell is an important information channel that is strongly linked to emotions and memories. The stimulus of a scent can evoke memories that are more emotionally loaded than memories elicited through other senses. Contextually distinctive odors are especially good retrieval cues [11]. Furthermore, long-term odor memory is unusually well preserved beyond other sense memories [11]. Pleasant odorants can improve mood [1], may affect the quality of life and there is suggestion that a reduced odor perception can be linked to mental discomfort [25].

Figure 1. The *inScent* prototype worn on a necklace.

When perceiving the environment, smell is often an essential part of the experience, e.g. smelling the leaves and trees when strolling through a vivid forest, or the familiar and intimate smell of the own home. But also indepentently, artificial scent is used to create or enhance experiences. Perfume gives oneself a pleasant personal scent, while for instance Mercedes-Benz offers a package to their premium cars that adds digitally adjustable fragrance to the air conditioning system. In aromatherapy, essential oils are used for expected personal well-being and many cosmetic products contain fragrances. Human perception of smell is highly variable with people varying in their general olfactory acuity as well as in how they perceive specific odors [15]. This makes it difficult to design for particular experiences equally among users. Nevertheless, smell inherently contains information about the state of things in our vicinity, like the smell of a burning fire [14].

The unique properties of olfaction as a modality make smell-based interaction a promising field for HCI. We want to utilize artificially emitted scents to invoke emotions and experiences for users in everyday life situations by presenting *inScent*, a wearable olfactory display that can be worn as a pendant on a necklace (see Fig. 1). The primary use case is to complement and amplify received mobile notifications by using scent as an additional *emotional notification channel*. We call this *scentification*. Messages of the life partner can be emphasized

ISWC'17, September 11–15, 2017, Maui, HI, USA.

ACM 978-1-4503-5188-1/17/09...$15.00.
https://doi.org/10.1145/3123021.3123035

by emitting a pleasant relating scent such as flowers or the other persons perfume aroma to reflect the emotional link to this person (see Fig. 6). Another example is using the alerting properties of smell to subtly remind of an upcoming event (e.g. a meeting). Our device contains up to eight different scent aromas in exchangable scent cartridges that can be used for different applications and use cases. Upon emission, a scent aroma is vaporized. A small fan within the casing flows air through the device and gently blows scent towards the user's nose.

The main contributions of this papers are (1) a novel unobtrusive, wearable and miniaturized olfactory display that allows passive amplification of received notifications with scents, (2) the presentation of an open source hardware and software framework that allows developers and researchers to add scents to their mobile applications and use cases, and (3) a qualitative user study investigating the users' perception of *scentifications* in public.

RELATED WORK

Kaye encouraged the HCI community to use aromatic output [13] and to explore the symbolic properties of smell in his thorough work [14]. He suggests that the peripheral qualities of scent make it ideally suited as an ambient and calm display. As a conclusion, users are better able to find meaning in the *quality* of different distinguishable scents than in the *quantity* (i.e. intensity) of single scents.

Obrist et al. [23] collected smell experiences and the accompanying emotions via user stories in a large scale online study. Smell was i.a. associated with memory and remembering past events, as a stimulus and desire for more, and as a means to detect immediate events (such as a gas leak).

Applications for Smell in Human-Computer Interaction

Computer generated smell has already been used in a wide variety to enhance the experience and immersion in multimedia. First attempts date back to the 70's with the Sensorama simulator using smell among other modalities such as vibrations and wind to increase the immersion of a motion picture [10]. Ghinea et al. [9] showed that olfaction significantly adds to the user multimedia experience. Nakamoto et al. [20] used scents for an interactive virtual cooking game. For smelling screen [16], odor can be distributed on a display screen by fans on the corners, so that users can lean forward to smell and find the virtual odor source. With the MetaCookie+ [21], it was shown that the perceived taste of food can be altered by changing appearance and scent.

Brewster et al. used smell for memory recall of photos in digital photo collections where users could tag and search by different odors [5]. The properties of different output modalities as a notification mechanism were explored by Bodnar et al. [4]. They found that olfaction is less effective in delivering notifications but also produces a less disruptive effect in the primary task.

For SensaBubble [26], sight and smell are combined in a projected mid-air display. Generated bubbles are filled with fog that contains a scent relevant to the displayed notification. The user can first see the notifcation and then smell it upon bursting the bubble, so that the information is changing its modality.

Scent can also be used to express unique identity. For Sound Perfume [7], a personal sound and perfume is emitted during interpersonal face-to-face interaction. Whereas for Light Perfume [8], the idea is to stimulate two users with the same visual and olfactory output to strengthen their empathic connection.

Kaye defined scent used to convey information, where the scent is environmental and semantically related to the information conveyed, as a 'smicon' [14]. Examples were to use ambient smell to convey whether the stock market had gone up or down, using scent as a personal reminder (e.g. the smell of baby powder to be reminded of picking up the kids) or as a tool to provide presence awareness and a feeling of connectedness in relationships.

Scent Generation Methods

Unfortunately unlike other modalities like vision, dimensions of smell are not as well understood and cannot be coded as easily as color [13]. With our current knowledge, humans have approximately one thousand different kinds of olfactory receptors [27] in contrast to four kinds of receptors for vision. Up to now, no systematic abstract classification scheme could be established [13], so that scents are classified by resemblance with entities, e.g. the smell of a lemon. This is a problem for creating arbitrary scents on demand and leads to olfactory displays being limited to defined sets of scents. With *inScent*, we allow the user to decide which scents resemble relevant personal information by designing small scent cartridges that are easily exchangable (see Fig. 5).

For computerized scent generation, scented air has to first be made from the stocked form of odor material and then delivered to the human olfactory organ, i.e. the nose. Scents can be released by either natural vaporization, accelerated by air flow, by heating or by atomization [31]. Natural vaporization implies that high-volatile chemical substances are released over time as ambient scent due to air exposure such as with worn perfume. This releasing process can be accelerated by feeding fresh airflow. Heating can be used to release larger quantities of chemical compounds. Some compositions however can be denatured by high temperature. By atomization, a fine mist of scent is emitted, e.g. by a sprayer, diffuser or by using ultrasonic waves. However, much like sprayed perfum, the fine mist of atomized scent is adhering to surfaces and then continuing to naturally vaporize over time, making it less appropriate for *scentifications* that rely on temporary scent delivery. Heating has the advantage that very small vessels can be used to carry the odor, that intensity and timing can be controlled by the heating duration and that scents can be generated almost instantaneously [22]. For these reasons, we used vaporization by heating of essential oils mixed with highly viscous carrier liquids. An axial fan is used to deliver the scented air towards the user.

Olfactory Displays

Olfactory displays in related work are mostly stationary. With stationary emission it becomes challenging to create localized rather than ambient odor [29]. Yanagida et al. [32] built a remote air cannon launching small toroidal vortexes of scented air towards the user's nose tracked by computer vision. This however had the problem that users would feel an unnatural airflow when the vortex ring was hitting their faces. As an improvement with SpotScents [19], two air cannons were used to let two scent vortexes collide at a target point in front.

To simplify scent delivery, users can actively move an olfactory display towards their nose. For Fragra [18], the device is mounted on the user's hand, for Scent Rhytm [6] on the user's wrist, while Brewster et al. [5] used multiple graspable smell cubes each containing different odors. This however implies that the user actively has to initiate the delivery process by moving the scent towards their nose instead of passively receiving scent by the system, making it inadequate for scent-based notifications.

Warnock et al. argued that the inherent trait of olfaction as a modality is that notifications are slow to deliver [28]. To minimize and synchronize delivery and exposure time Noguchi et al. [22] used pulse ejection, whereby scents are only emitted for very short periods. The user however has to be positioned immobile in front of the stationary device.

In wearable systems so far tubes have been used to convey scented air towards the user's nose [30][21]. These are designed for virtual reality and are arguably too invasive for everyday life contexts.

Choi et al. [7] built a perfum actuator into a pair of 3d-printed glasses. The actuator was located behind the ear and emitting ambient scent by melting solid perfume. The scent-emission however could not be evaluated due to technical issues with the system. Multiple commercial attempts have been made to create smell devices (e.g. DigiScent's iSmell), however most were stationary and none was truly wearable yet to be used by users to passively receive scents throughout the day in mobile situations. Scentee [12] is a mobile scent dispenser that can be attached to the earphone jack of a smartphone and thus be carried along. However only one aroma is contained and the user has to actively held the device in front of their nose.

McGookin et al. developed Hajukone [17], an open source olfactory display to enable researchers to replicate the device for scent-based use cases. Similar to invasive solutions [30][21], however, the large form factor restricts users from wearing the device in public. Amores et al. [2] build an olfactory display that is wearable and releases scent throughout the day to affect the wearer's mood and wellbeing. The device is small and fashionable, but limited to a single scent to have an effect on the user.

WEARABLE OLFACTORY DISPLAY

We introduce *inScent*, a wearable olfactory display that allows users to passively receive multiple computer generated scents in mobile everyday situations. We utilize this to investigate the use of scents to amplify notifications, i.e. *scentifications*, in public scenarios.

To built a wearable device, a lot of design challenges have to be faced, starting from miniaturization and a small form factor up to battery usage and connectivity. We miniaturized an olfactory display as much as possible while at the same time enabling developers and researchers to replicate the device. All files are made available as open source. The utilities used in our work can be found in a well-equipped research facility. We believe that with industrial effort the device can be miniaturized even further.

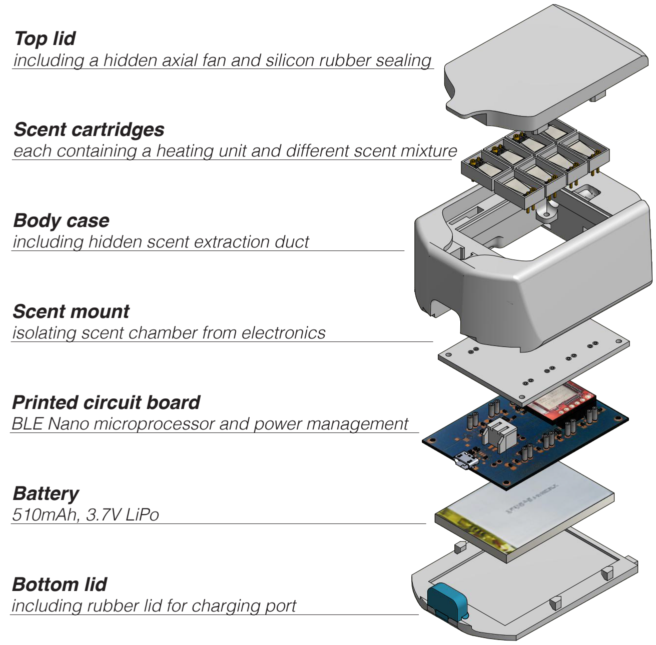

Figure 2. Overview of the assembly of the *inScent* prototype.

Form Factor

Miniaturization is a challenge in wearable computing, especially for a device aiming to emit different chemical compounds. A small size and low weight is needed to make the device suitable for daily use, while the limited space must be sufficient to contain aromatic substances and a scent emitting technique that is efficient in both, scent delivery and energy consumption. We decided to build the device in a form factor so it can be worn as a pendant around the neck. Other possible on-body locations could include integration in a shirt collar, a shirt pocket, or into a pair of glasses, however this would require further miniaturization.

For replicability, the casing (8.4 x 5.9 x 3.1 cm) was 3d-printed using an *Ultimaker 2* and PLA filament. The main body serves as a mounting device for the other components and represents the core element of the casing (see Fig. 2) containing the scent chamber, ventilation system, control unit, power management and battery. We made sure that the system is reasonably sealed using a locking system (see Fig. 4), but still allowing users quick access to the scent chamber by opening the top case lid.

Vaporization by Heating

Vaporization by heating is used for scent generation to be able to control timing, duration and quantity of the scent emission which is important for the use of *scentifications*. High temperature required in a small device worn at the user's body poses a safety risk, so that we had to be careful with the design decisions and materials used in the scent chamber.

The heating process for each scent aroma is conducted within the respective scent cartridge (see Fig. 5). Scent cartridges are designed to be simply producible and feature a modular design. They are very small (10 x 15 x 5 mm), can be filled with different scent aroma tailored to the user's and application's needs and are quickly exchangeable and pluggable into the device on the fly. Cartridges are designed to be flat but with a

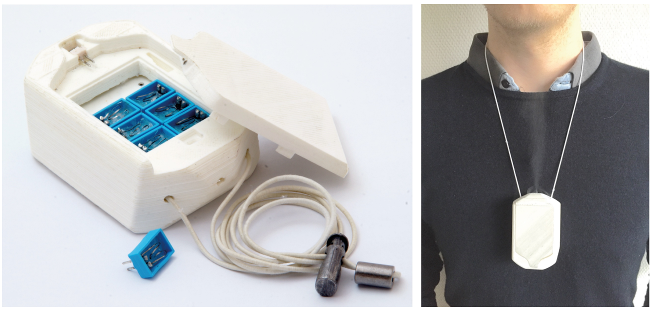

Figure 3. Left: The *inScent* prototype with opened top lid. Up to 8 scent cartridges can be plugged in. Each cartridges contains highly viscous scented liquid soaked into glass fiber to deter leaking. Right: Normally, scent emission is not visible to the eye. For this photo, we highly increased the amount of glycerol to make the scent emission visible as smoke.

wide surface area to increase the evaporation efficiency. Each cartridge incoperates a wire as a heating coil. We use Kanthal A-1, a ferritic iron-chromium-aluminum alloy that is often used for electrical heating elements since it can withstand high temperatures and is simultaneously characterized by a high electrical resistance. As a downside it is not solderable. This is why two clamps are used to hold the coil in place. The clamps are soldered to two pin heads which serve as a plug to connect to the mainboard and hold the cartridge in place.

An absorbing layer consisting of glass fiber is located underneath the heating coil (see Fig. 5). It absorbs the scented liquid and consistently delivers liquid to the heating coil. In addition it prevents the scent cartridge from leaking. Glass fiber cord is favorable over other absorbing material such as cotton pad, due to high resistance to temperature (over 1300°C) and because it is odorless.

The scented liquid is a mixture based on aromatic substance, high-proof alcohol and carrier liquid. Initially, the aromatic substances (ethereal oils) are pre-diluted with ethanol. Subsequently, the solution is mixed with a carrier liquid consisting of glycerol and polyethylene glycol (PEG). Both carrier liquids are highly viscous. In conjunction with the liquid mixture being soaked into the absorbing layer (i.e. the glass fiber), the high viscosity prevents leaking from the scent cartridge. For easy access and due to space limitations, all cartridges share a common scent chamber. McGookin et al. [17] argued that scents must be contained individually to prevent scent mixture and natural vaporization over airflow. We didn't face these problems by carefully choosing the intensitiy of the aromatic substance, so that natural vaporization does not expose a perceivable amount of molecules, but that when heated enough scent is released to have an effect on the user. The mixing ratio was determined experimentally and was for instance 5% aromatic substance, 20% ethanol, 50% glycerol and 25% PEG for the scent aroma *orange*. The amount of aromatic substances can vary due to human olfaction perceiving different odors at varying intensity (e.g. we used only 2% aroma for *mint*). For mixing liquids a pipette and micro test tubes were used.

To seal the scent chamber from the top lid, a silicon rubber sealing was casted (see Fig. 4) using a 3d-printed negative mold and a two-component silicone. This represents an important safety factor. The silicone is thermally stable up to 180°C and insulates the lid's PLA filament from heat emission. For

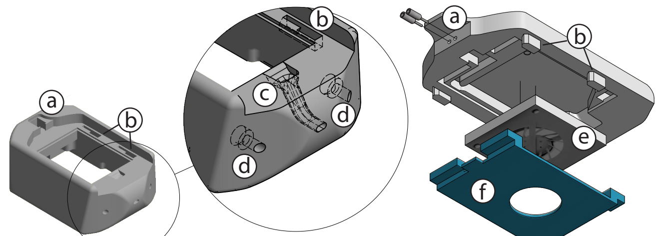

Figure 4. Detailed view of body case (left) and top lid (right). The top lid slides into the fan connector (a) and locking system (b). Scent is emitted over the extraction duct (c). The mounting (d) can hook a necklace. An axial fan (e) vacuums scented air from the scent chamber into the extraction duct (c). Silicon rubber (f) seals the top lid with the body case and serves as a thermal protective layer.

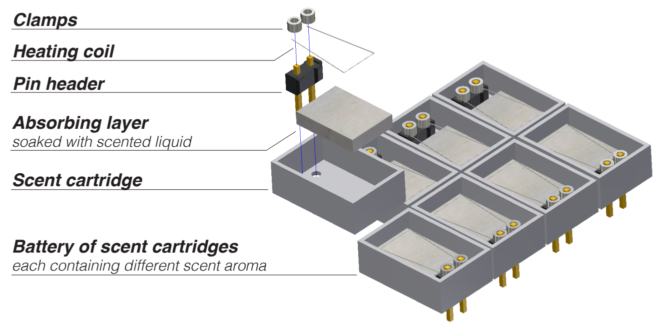

Figure 5. Overview of the scent cardriges with integrated heating units.

safety reasons we also isolated the scent chamber from the in-built electronics and battery by an extra layer (see Fig. 2).

Scent Delivery

After vaporizing scented aroma, the scented air has to be delivered to the user. A small axial fan[1] (30 x 30 x 3 mm) is embedded in the top lid and vacuums the vaporized scent from the scent chamber and exhales it into a scent extraction duct (see Fig. 4) on the upper side of the device facing the user's head. The fan maintains a static pressure of 88.18Pa, corresponding to 17.74l /min at a low noise emission of 28.7dB(A). Even smaller (down to 10 x 10 x 2 mm) fans were tested but they provided insufficient air pressure for the user to smell the scents. For scent emission, the fan, as well as the heating coil in the scent cartridge are powered for 5 seconds. Scented aroma vaporizes almost instantly in the scent chamber, but then takes a few seconds bridging the distance to the user's nose.

Power management

The axial fan operates between 2.0 - 6.0V and has very low energy consumption of maximal 72mA resulting in a low battery drain. For power supply we built-in a Lithium-ion Polymer (LiPo) battery that provides 3.7V and a nominal capacity of 510mAh. The battery has small dimensions (34.5 x 52 x 3.5mm) but provides a maximal discharge current of 1020mA making it suited to meet the high discharge requirements during the scent release.

For *inScent* to be able to receive *scentifications* from a connected mobile device and to then drive the scent release, a *BLE*

[1] Sunon UB5U3-700 `http://www.sunon.com/`

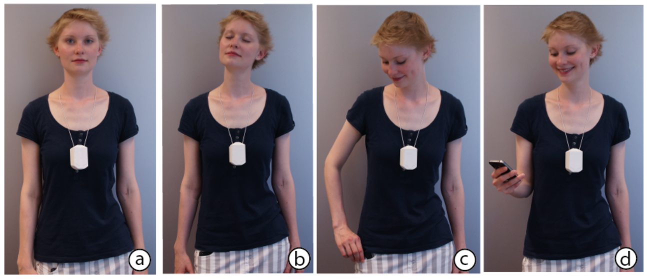

Figure 6. A user receiving a message of her parthner (a). She smells his scent (b) and in pleasant anticipation reaches for her phone (c) to read his message (d).

Nano[2] was integrated. It has a low power consumption and is one of the smallest Arduino microcontroller on the market that incoporates Bluetooth Low Energy (BLE) functionality.

We manufactured a double-sided printed circuit board (PCB) to mechanically support and electrically connect all electronic components. The conducting paths are designed to support both high current frequencies and currents up to 2A. This enables individual voltage values between 0 and 3.7V through pulse width modulation (PWM) signaling with different currents. The board features a slot for each scent cartridge over which the *BLE Nano* is capable of measuring current. This enables polling each slot to detect plugged-in scent cartridges. However, by itself the *BLE Nano* has only a limited output voltage of 3.3V and an output current of 0.5mA which is not sufficient to directly power a scent cartridge to release scent. This is why the slots draw the power directly from the battery which is switched by a transistor.

The board can be powered via battery or micro-USB. In addition, an integrated linear charge management controller allows charging the battery via the USB-port. The controller has an integrated current sensor to prevent the battery from overvoltage and thus overheating.

Including all components, the *inScent* wearable weighs 102g, can be used multiple days without recharging the battery and each scent cartridge contains aroma for approximately 70-100 *scentifications* (depending on intensity). All assembly files, instructions and software are made available as open source at `https://www.uni-ulm.de/?inscent`

SOFTWARE FRAMEWORK

To be able to use the *inScent* wearable in daily life and to open new application areas we built a comprehensive mobile software framework for the user's phone running on Android (ver. 5.1). The framework runs as a background service that can be accessed by one or multiple applications. It is in charge of the control flow of *scentifications* including the connection with the device. For a developer, the development of a new scent-based application is simple by implementing an existing interface and installing the *inScent* framework on their phone.

Scented notification

The framework allows to automatically amplify the phone's native notifications with emitted scents. A developer can define multiple trigger and events such as the name of the sender, the content of a message or a particular application (in any combination). Also timing conditions are possible (e.g. 5 minutes before a specified calendar event).

Remote service

To also enable remote control for developers, we implemented a GCMService that allows the sending of push notifications over Google Cloud Messaging (GCM) direcly to the running background service . This enables access to the framework from outside the phone and allows for its integration into other systems independently of system platform or programming language. External systems are able to remotely emit scents for varying use cases. It is also possible to remotely change the device configuration (e.g. to integrate new events)

To release a scent from any application implementing the interface, it just has to send a message to the background service:

```
sendCommand(new Command(commandType,slot,intensity));
```

Commands are validated by the service and additionally on the *BLE Nano*. Messages with invalid slot number or intensity are withdrawn. This way, the system can prevent misuse. It also validates whether the addressed cartridge is inserted.

We developed an exemplary application implementing the interface that we use for the user study that allows the user to release different scents via large icons in a user interface and the instructor to remotely send messages and emails that trigger scents related to the respective incoming notification.

USER STUDY

We conducted a qualitative user study to learn from a first-hand user perspective about *scentifications* in wearable contexts in public. In previous work it was shown how scents can be used as notifications to convey information (e.g. [14][4]). These systems however were stationary and emitting *ambient* scents. In contrast, we want to investigate the properties of personal *mobile* scents. For our user study, participants wore the *inScent* prototype while walking through a heavily frequented university as a public scenario and received a scripted set of different notifications on a phone that each triggered an additional scent. Subsequently, in semi-structured interviews, we asked participants about their impressions and concerns and used grounded theory to build a common understanding of the experience to learn about the use of scented notifications in wearable contexts.

Procedure

We recruited 16 participants between 20 and 31 years (M=26.13; 7 female). The study lasted about 60 minutes and started and ended in an office room where the participant was made familiar with the *inScent* prototype and the concept of *scentifications*. Beforehand, we asked for any medical condition, e.g allergies against certain scents or having a cold, that could negatively affect the participant or the perception of smell. We handed over the wearable device and a complementary Android phone running the background service.

Four different scent aromas were used (flowers, mint, lavender and lemon) and inserted as scent cartridges into the device with help of the instructor. The first scenario for the participant was to manually trigger any of the four scent aromas via an app on the phone as *Ambient Smell*. This also served to familiarize with the four scent aromas. Afterwards

[2]BLE Nano `http://redbearlab.com/blenano/`

Figure 7. A participant wearing the *inScent* prototype in public during the user study. As an assignment, they would buy a chocolate bar in the university cafeteria. Participants received an enforced *scentification* while lining up and another while at the cashier.

the participant was asked to individually assign the given scent aromas to four scenarios that were used for scripted *scentifications*:
(1) *Scented Message*. Received messages of an important person (e.g. the life partner) were complemented with a scent to reflect the emotional link to this person. The person would send multiple messages throughout the study such as asking when the participant comes home.
(2) *Scented Reminder*. Calendar events were complemented with a scent to subtly remind the user for the next task in the user study.
(3) *Scented Event*. The user eagerly awaits the delivery of an important parcel. The scent would be released for updates with the delivery process.
(4) *Time Sense*. A scent to trigger a feeling for the passing of time. We used a scent indication every quarter-hour to guarantee at least 3 events during the study.

These scenarios were to help participants understand the concept of scented notifications. We restrained to four scenarios with four scents to make it easier for participants to quickly accommodate.

After assigning scent aromas, the participant put the *inScent* wearable around their neck and the phone into their pocket. The instructor was also wearing a (functionless) *inScent* wearable to lower the inhibition level and a phone to control the user study. Instructor and participants then left the office room and strolled through the university as a public setting that is heavily frequented. The route was guided by the instructor and equal for each participant. It included two elevators, various corridors, three floor levels and dwelling for a while at three open locations with many bystanders. This part of the user study lasted around 15 minutes and included 12-15 scripted *scentifications*. In addition to emitting a scent, the participants phone would vibrate and the content of the scripted message was displayed (e.g. the partner's message). Part of this setting was for the participant to walk into the university cafeteria, to get into line, and to buy a chocolate bar. The presenter forced a *scentification* when the participant was lining up, another when paying at the cashier and another when standing within an elevator (with other people). Other *scentifications* were scripted over time. During this study part small talk was used to distract the participant from solely trying to smell.

Following this, a semi-structured interview was conducted in the office room for at least 30 minutes and audio recorded. The interview started with remarks and comments that came up in the previous study part. Themes that were explored spanned possible improvements for the prototype, benefits and limitations, social acceptance, application scenarios, scents in everyday life and the perception of scent in general. Participants received €8 and a chocolate bar for compensation.

Analysis

The analysis process followed an open coding approach [24] by two researchers. The audio recodings were transcribed into text files. We used initial coding along the study process on the transcribed text and generated 120 initial codes on user statements, followed by holistic and subsequently axial coding grouped into 31 axial codes. Codes are emphasized in text.

Design

Participants appreciated the amulet form factor as masking the scent emitting device as being **jewelry**. A **fashionable design** was noted to be important. However, as fashion changes with context "I wear different jewelry every day" (P12) there was also the notion of reaching for a **subtle design**. With that in mind our prototype received compliments, nevertheless, an ideal device was desired to be smaller and to weigh less. There was worry what **impression on others** is made by the design and form factor, especially whether the device exposes itself as scent emitting "I don't want to be referred to as an esoteric" (P15), "I fear that people might stare at me" (P1). Thus, the design should be **unobtrusive to others**.

Subtlety

Scents diffuse and can be smelled by bystanders depending on intensity and dispersal. Therefore, participants preferred scent notifications to be **subtle in intensity** "if the scent was incredibly penetrating and unpleasantly smelling, I would be really ashamed" (P8). On the on hand, participants were worried about the **smell perception of others** "I have the feeling people can be bothered. Like when wearing too intense perfume" (P6). On the other hand, some participants stated they wouldn't mind leaving a scent. Locations with little air circulation such as offices, meeting rooms or elevators were mentioned to most likely let scent affect other people. Multiple participants stated they didn't think of a negative impact on bystanders "I cannot imagine that anybody would be annoyed by a light breeze of pleasant scent" (P8). In general, the scents were perceived as **pleasant** and **non-disrupting**. "The scent is more subtle... (in comparison to other notifications). It is rather a subtle polling than an interrupt" (P6), "I think it is a very pleasant kind of notification, especially if one doesn't want to be interrupted and rather stay focused" (P7).

Our prototype had a fan that could faintly be heard in quiet surroundings such as the empty office room. An ideal device should be **noiseless** to support subtlety.

Scent aromas could easily be dinstinguished, however, participants often had problems remembering the assigned scenario. In this regard, participants did not build a strong association of scent and the respective meaning over the course of the user study. One exception was the flower (ylang-ylang) scent aroma which was assigned to the *Scented Message* of the life partner by all participants. Scent aromas could not be perceived by the instructor, even though being close-by the participant throughout the study. One notable exception was when walking directly *behind* the participant. When in motion, scents were generally more difficult to perceive by the participant. When walking with a fast pace, the resulting air draft would pull most of the scent over the user's shoulder. As a result, participants would slow their pace when getting a notification (i.e. when feeling the vibration). This suggests that motion detection would be helpful to adjust the intensity [3] by creating a stronger air flow.

Control
Participants mentioned prefering to receive *scentifications* at familiar or personal places over public ones. To be comfortable with the device, they wanted to feel like being **in control** of when a scent can be emitted and when not. This behavior might change over time, when the user becomes more familiar. Ideally the device is aware of its context. Nevertheless, it should allow the user to easily *silence* its scent features, which was not implemented with our prototype but a requested function.

Contrary to feeling the need to be in control, participants appreciated the emission of scents being a **background activity** that can subliminally work on the user.

Pollution
Since scents linger and can add up in intensity, a high frequency of *scentification* can be perceived as **smell pollution**. **Overuse of smell** within a short amount of time is therefore a rather bad idea so that frequency should be controlled, e.g. a *Scented Message* would only trigger for the first message of a conversation instead of for every new reply. Also other people might have **allergies** to certain smells so that smell extent should be limited.

In some contexts, *scentifications* are prone to **superimpose smell** that is part of a pleasant experience "When eating I don't want to perceive other smells" (P4) "I wouldn't wear it when I am going out to eat with someone" (P3). On the other hand, the device can be used to **cover unpleasant smell** "I like to be able to adjust the ambient smell" (P11). Depending on context, emitting a scent can create or disrupt a smell experience, which leads back to the user's desire to be in control.

Scent as a different notification channel
Using scents for digital notification was seen as being **novel** "It is a completely different channel that is unknown to you" (P8), "It is a novel experience" (P15). It allows for "**multidimensional feedback**" (P6) in combination with audio, visual or tactile stimulations. One participant (P16) stated that she was overwhelmed by getting so many visual and audio stimuli in a crowded and noisy environment that it made it difficult for her to perceive smell leading to a **sensory overload**. In contrast to other modalities for notification, such as sound or vibration, smell was generally seen as more pleasant and positively connoted.

Reliability is important when it comes to conveying information. Depending on context however *scentifications* could be missed or misinterpreted. In one case, a bystander peeling an orange led to the participant checking his phone in anticipation of a notification. Another participant (P1) claimed to be bad at identifying different smell. As a conclusion important information shouldn't be solely conveyed by smell, so that smell functions as an **additional channel**. Becomming **accustomed** to certain smells can be positive to build up strong associations to the underlying information, but also negative when a user is getting less sensitive to it "When smelling it every day my senses could deaden to it" (P2).

In contrast to other notifications, scents have the inherent property to **linger**. The scent is getting stronger over a short period of time when getting emitted and then slowly disperses and getting weaker. This is unlike the *hard* event of a vibration or ring tone and was mentioned as being favorable by participants "It is not a hard event, you slowly realize its presence. It is not an alert but rather an impression that emerges" (P9).

Scent is very personal
Scents are perceived differently in intensity, liking and association by each person. **Individualization** allows each user to find their personal taste. With our prototype this was enabled by easily exchanging scent cartridges, but also by inserting up to eight scents at once. Ideally a wide variety of these is offered so that every user can find their **individual scents**. Individual scents can allow you to build a very **personal association** and coding to information "Scents can ultimately be very well coded. Even when a bystander can smell the scent they still don't know its meaning. Only I have this information" (P8). However much like the user being able to build a strong association, this might be possible for related persons. For example, for a *Scented Message* friends or office neighbors might be able to **decode the meaning** after a while by context and continued exposure.

Utilizing Emotions
Scents have a very strong link to emotion, thus *scentifications* can be used to add an **emotional channel** to information. Emotional response to a certain smell however is individually different so that it is probably better to let the user decide over a scent than having it assigned by a developer: "The smell of Lavender has a strong connection to our wedding" (P8). A *scentification* can create a **pleasant anticipation** of an event "It is really nice that you get pleasantly thrilled first when smelling the message and then when you read it" (P10).

Scents can also be used to actively **set** or to **support a mood**. Participants suggested they could use scents to animate or reduce appetite, enhance concentration, or to get an relaxant or refreshing effect, i.e. using the device as a mobile personal aroma lamp.

Keyfindings
The study has shown that *scentifications* can be used to convey information in a wearable context. From the findings we can learn that social acceptance, as with other wearable devices, is a crucial factor and that potential users feel uncertain whether bystanders can perceive scents and how they might react. For this reason the overall design should aim for subtlety and unobtrusiveness. Bystanders during the user study did not show indication for perceiving scents, which suggests that subtly using scents in mobile scenarios is feasible.

Smell is inherently different from other output modalities by its traits. It is less reliable, but also perceived as less-disruptive and can be very pleasant. Individual scents can add anticipation and emotion to the moment of being notified and entail a very personal meaning. For this reason, *scentifications* should not act as an replacement for other output modalities, but rather complement to convey addtional meaning, i.e. to *amplify* a notification. During the study multiple participants mentioned feeling generally more aware of the smell of different places than usual. They experienced this as very positive, so that *scentifications* do not only superpose the sense of smell but might help in stimulating its cognition. Moreover, participants were excited about this novel way of passively perceiving information, illustrating that the use of scent in wearable context offers promising possibilities for human-computer interaction.

CONCLUSION AND FUTURE WORK

inScent is a wearable olfactory display that allows the emission of scents throughout the user's day as a mobile amplification for notifications. Users can individually assign scents to applications and use cases using modular scent cartridges, while developers and researchers can create novel scent-based applications for wearable contexts using the introduced hardware and software framework. The potential of scent-based notifications has been investigated in a qualitative user study in public. Our findings offer guidance to design scent-based applications for wearable contexts.

In the future we want to conduct longer qualitative user studies by letting participants wear the device over the course of several days to learn how users adapt to scent-based applications in the wild. Also we plan on conducting quantitative indoor and outdoor experiments. We assume that outdoor conditions, e.g. wind and ambient smell, will make scent recognition significantly more challenging. During testing, we used smoked scent to track and optimize the scent delivery process (see Fig. 3). This caught our interest in investigating purposefully emitted scented smoke as a cue for users and bystanders. So far we focused on enhancing notifications. Scents however could also be used to help keeping and recalling memories. By this, users could actively use a distinctive smell when experiencing a nice situation to later help recalling this event. Other possible use cases for *inScent* span more traditional applications like multimedia enhancement and immersion in virtual reality.

ACKNOWLEDGMENTS

This work was conducted within SFB/TRR 62 Companion-Technology for Cognitive Technical Systems and the Emmy Noether research group Mobile Interaction with Pervasive User Interface both funded by the German Research Foundation (DFG).

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