When Do You Light a Fire? Capturing Tobacco Use with Situated, Wearable Sensors

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Abstract

An important step towards assessing smoking behavior is to detect and log smoking episodes in an unobtrusive way. Detailed information on an individual's consumption can then be used to highlight potential health risks and behavioral statistics to increase the smoker's awareness, and might be applied in smoking cessation programs. In this paper, we present an evaluation of two different monitoring prototypes which detect a user's smoking behavior, based on augmenting a lighter. Both prototypes capture and record instances when the user smokes, and are sufficiently robust and power efficient to allow deployments of several weeks. A real-world feasibility study with 11 frequently-smoking participants investigates the deployment and adoption of the system, hinting that smokers are generally unaware of their daily smoking patterns, and tend to overestimate their consumption.

Author Keywords

Wearable sensing, smoking detection, augmented tools

ACM Classification Keywords

H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces, Evaluation/methodology.

Introduction and Motivation

The World Health Organization calls tobacco use the single most preventable cause of premature death [11], presenting both a personal health risk and an increased load on public healthcare systems. Recent studies in the US estimate the annual cost of treating smoking-related diseases and caused productivity loss to $\$191$ billion [17], in the EU up to €313 billion [6]. However, smoking cessation is often hindered by the low perceivability of health risks in day-to-day life, and effective smoking cessation systems, besides personal counseling, are still in need to be developed further.

Interactive and personalized intervention systems including printed self-help material, text-messages and websites have been shown to increase successful cessation attempts [18, 16]. These intervention systems tailor information according to questionnaire-based self-awareness reports which elicit the different motivations for cessation and the smoker's behavior change stage, i.e., they match information to the smoker's behavior. A recent pilot study [2] has shown that by providing smokers with a personal sensor, the *Smokerlyzer®* [15], they are able to reduce their consumption to a preset goal. One drawback of these systems, with the exception of text-message based ones, is that they cannot intervene when a cigarette is lit up to provide timely feedback, e.g. giving feedback while a cigarette is being consumed.

Persuasive technologies [5] have an unprecedented ability to monitor one's health and lifestyle, and as such can equip users with novel tools to improve on self-monitoring, self-discipline and reflection to motivate lifestyle changes [8]. The increasing set of off-the-shelf products that are able to provide feedback, analysis and visualization of the user's fitness activities, sleep patterns, or sedentary episodes, indicates that there is a large interest in such technology beyond healthcare scenarios. Such technologies have furthermore been adopted as key components in diagnosis and analysis for clinical and psychiatric studies [4].

This paper focuses on the detection and long-term capturing of users' smoking episodes throughout the day, using data from light-weight and inconspicuous sensor devices. We present the prototypes of two versions of instrumented lighters which log the time-of-day of their usage. The captured data is collected via a USB connection and presented to its users after several trials lasting at least four days. We investigate how the collected statistics on personal smoking behavior can increase the users' self-awareness, and we argue that such statistics can increase the effectiveness of interactive smoking monitoring programs. Tailoring information via such quantifiable behavior can then be the basis for providing game-like competition for the motivation for cessation, and further increasing self-awareness through the addition of contextual information.

Our contributions are twofold: First, we present a new sensor modality, the cigarette lighter, that lends itself well for long-term monitoring of cigarette consumption, without requiring explicit interaction or attention from the user carrying the device. We present two design iterations for a real-world-deployable prototype, called *UbiLighter*. Second, through surveys before and after a deployment, we have performed a feasibility study to investigate user adoption and to compare reported smoking behaviors with the measurements of the UbiLighter.

The remainder of this paper is structured as follows: after an overview of related work in this area, we discuss the two prototype iterations that were built during the course of this research and detail the underlying challenges in making these devices robust and power-efficient enough for long-term deployments. We then report on user adoption in an evaluation section with a real-world feasibility study with frequently-smoking participants, and show significant differences in their time-of-day consumption patterns.

Related Work

A number of research projects have studied tobacco use by means of automated and semi-automated sensing methodologies. This section provides a concise overview of the literature, with a particular focus on wearable and situated monitoring methods reported on to date.

Several wearable systems to monitor a user's smoking behaviour have been reported. Sazonov et. al. report on a hand gesture sensor which can track the distance between a miniature RF transmitter worn on the wrist and an antenna worn on the chest [13]. This results in very exact measurements (in the sense of confusion with other everyday gestures) in the absence of RF interference, is however limited to detecting gestures of the dominant hand. This sensor design has been used in addition to a wearable plethysmograph and self-report button by Lopez-Meyer et. al. [9]. A support vector machine has been used to identify smoke inhalations in the measured chest movements with a precision/recall of 90% in a lab setting with 20 participants. A week-long study with respiration measurements (plethysmography) has been conducted by Ali et. al. [1], which has shown that a support vector machine classifier can identify smoking episodes on per-subject basis.

A wrist-worn accelerometer is another possibility to detect the quite distinct wrist gesture performed while smoking a cigarette [14], which is however also limited to gestures of the dominant hand. Despite not being a wearable system, Wu et. al. [19] have shown the possibility of detecting smoking incidents from camera images. Most in line with the motivation of the work presented here is the report by Beard et. al. [2], in which the *Smokerlyzer* sensor has been used to quantify a smoker's consumption behaviour. This personal CO-monitor analyses a users' breath at regular time intervals to find out how many cigarettes have been smoked throughout the day, but has shown to be hard to adapt for day-to-day use, which hinders long-term usage. It has however been shown that setting a clear-cut goal to reduce cigarette consumption with the addition of such an unbiased feedback mechanism can help smokers to reduce their cigarette consumption.

Furthermore involving additional media like mobile phones to design health intervention have been reported. An excellent review of mobile phone based (including text messages, website and native applications) interventions can be found in [7]. These interventions have the capability to be provided just-in-time, especially to "...detect such contexts could enable us to provide users with assistance before they engage in such unhealthy behaviors, as well as to provide post facto feedback, potentially greatly increasing the effectiveness of behavior change interventions". Similarly we see the robust detection of unhealthy behaviours as the first step to providing means for an intervention [10]. Such just-in-time intervention could for example be combined with systems like *StopAdvisor* [3, 16, 18], i.e. online cessation support systems that tailor information to the smoker. Especially the just-in-time delivery of support proves to be effective, as has been shown in a pilot study in New Zealand [12] with the *Txt2Quit* system. Since such systems do not have the ability to detect and log smoking episodes, they remain limited to what is explicitly provided by the users.

System design

In this section, we present the design of two prototype iterations which can be used to track the time-of-day and number of consumed cigarettes of their users. During the design phase we followed the guidelines layed out by Li et. al., especially to design systems which allow "collecting data anytime, anywhere and often", to "support different kinds of collection tools" and to "reduce the upfront cost of data collection" [8]. The next subsection will present the design of the two implementations of the proposed *UbiLighter*, an instrumented lighter that logs down its usage in the internal memory of a micro-controller.

UbiLighter – An Instrumented Lighter

Our prototype is motivated by the fact that monitoring the use of a cigarette lighter is a straightforward, robust and inconspicuous way to track a smoker's consumption behavior. Implemention of such a device is however aggravated by the availability of lighters that generate a measurable electronic signal when used. Currently, there are three lighter types widely used: gas, petrol and electronic lighters. Electronic lighters, like the ones found in cars, work by closing an electronic circuit which heats up a coil with a large current. Gas and petrol lighters generate a spark by some mechanical force that ignites highly flammable, evaporating material. This spark is either generated by scratching a flint stone or by the high voltage discharge of a compressed piezo element. These constitute the basic working principles of which a measurement mechanism can be deduced. For our prototype, we report on two iterations that were both deployed with frequently-smoking participants for an extended period. Both designs allow to log the time of day when the lighter has been used to light up a cigarette, with the first version of this prototype being based on the principle of a heating coil.

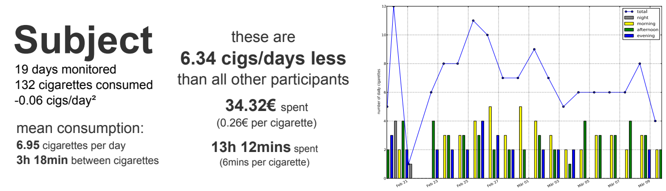

Figure 1: Example report generated for the study participants. The plot on the right side shows the amount of daily smoked cigarettes on four different times of the day. To the left are personalized smoking statistics as captured by the UbiLighter.

UbiLighter v.1: a Coil-based Lighter

The first iteration of the *UbiLighter* is based on an off-the-shelf electronic, rechargeable USB lighter which contains a 200mAh Li-Ion rechargeable battery and a coil. The contacts that shorten the connection of the included Li-Ion battery to the heating coil are in our first prototype re-used and connected to an Atmega32U2 microcontroller, a real-time clock (RTC), a USB port and two indication LEDs. This prototype thus allows the logging of every instance when the lighter is switched on with time-stamps, and the logged data to be downloaded afterwards via the USB port. The whole is wrapped up in the original case to ensure the prototype remains sufficiently robust to withstand day-to-day usage. The components of this first version are depicted in Figure 2.

The firmware on the micro-controller is designed to consume as little current as possible; During periods of no activity the micro-controller is in deep sleep mode and only wakes on USB activity or when the switch contacts change their state. Only the RTC is constantly drawing power, which leads the whole prototype to draw a standby consumption of $0.04\mu A$. Whenever the switch is moved, the micro-controller wakes up from sleep, lights up the status LEDs, reads the current time from the RTC and writes the time-stamp along with the duration of how long the switch was used (using 100ms as a unit) to internal memory. Each timestamp takes up $4B$ of memory, which allows to record a total of 255 occurrences in the $1kB$ sized internal memory.

Although this first prototype was found to work well in preliminary trials (see [14] for more details on those), several shortcomings were found that hinder more extensive depoyments. A first issue that some users experienced was the mechanism: this requires sliding down the switch for a considerable time to sufficiently heat the coil, which for several users was found to be both unfamiliar and not as pleasant as a traditional gas lighter. A more critical shortcoming though, was that due to the high power consumption of the heating coil the system runtime is limited to about two to three days for frequent smokers[1] before it needs to be recharged, which bothered several users and led to a few cases of missing data logs.

UbiLighter v.2: a Gas Lighter

Despite having a very different form factor, the printed circuit board for the second version of the *UbiLighter* contains essentially the same electrical components: The micro-controller is directly connected to the gas lighter's ignition contacts, which are the contact pads which get shortened when pushing the ignition button down (see Figure 3). A custom-made PCB populated with an Atmega32U2 micro-controller, a real-time clock (RTC), a USB port and two status LEDs, performs the logging of smoking instances as in the first *UbiLighter* version.

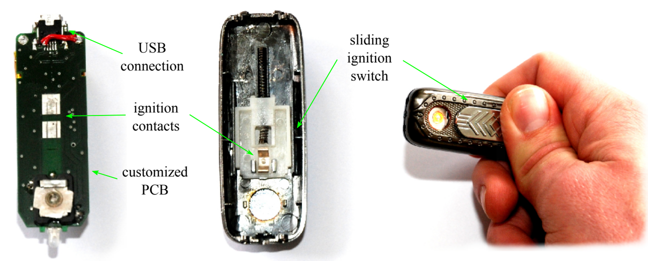

Figure 2: The UbiLighter v.1's internal buildup. On the left, a mechanical switch closes the circuit between battery and a coil, allowing it to heat up so that a cigarette can be lit up. The time and duration for which the switch was used is logged by an on-board micro-controller that is connected to a real-time clock. The right-hand side shows the lighter while being used.

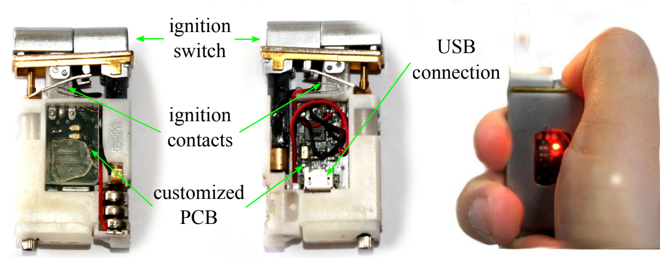

Figure 3: The UbiLighter v.2's internal buildup. The ignition contacts as read by the micro-controller are highlighted. On the left-hand side the battery compartment and LEDs are visible. The center shows the RTC, USB connector and microcontroller. The right-hand side shows that the lighter while being used operates very much like the traditional lighter.

Surges from the piezo when lighting up a cigarette can be avoided by provisioning a grounded enclosure nearby. The

[1]These figures depend on the number of smoked cigarettes, and are given for an average number of fifteen (15) cigarettes per day.

main improvements to the first version are (1) the more familiar form factor of a gas lighter, as well as (2) the fact that the three small LR41 coin cells included in the gas lighter provide 30mAh of power or about 20 days of continuous runtime before they need replacement.

The process of capturing and recording the smoking instances is for the second version similar to that of the first, though in this version it is not possible to time the switching: if there has been no write operation during the last 6 minutes, the timestamp is written into the internal non-volatile memory of the micro-controller. The 6 minute interval serves a double purpose: First, it is a simple mechanism to debounce the ignition switch and second, it filters incidents of multiple ignitions sometimes needed to light up a cigarette. The 6 minute interval has been chosen as the mean time taken to consume a cigarette[9]. The smoking incidents timestamps can be downloaded from the lighter via a virtual serial port emulated by the Atmega32U2 in `csv`-format for further analysis.

The USB port of UbiLighter's first version is directly accessible, while the second version has its USB port covered inside the enclosure, which needs to be opened to attach and download data to a PC. Although this makes the prototype highly robust, this version can provide long-term feedback only during maintenance phases. Further design choices considered for the UbiLighter include adding temperature or contact sensors and batteries to easily modifiable lighters like the petrol Zippo lighters, though it turned out to be a challenging task to ensure the electronics would not accidentally ignite the petrol. Generally, the inclusion of batteries and electronics in light-weight, commercial lighters that have not been mechanically designed to hold them is a hard challenge, as the only way to add them is either in the compartment holding the flammable fluid or on the case's outside.

Study Design and Experimental Results

This section details how the prototypes were deployed and used in an experiment by 11 participants, providing us data covering a combined timespan of about 2800 hours. We evaluated the two UbiLighter prototypes in a number of user studies. The 11 voluntarily participating smokers were recruited from the vicinity of Darmstadt through poster advertising, Table 1 summarizes base data of these participants. Three participants (number 8-10) were asked to use version 1 (coil-based Lighter), while eight others (number 0-7) were asked to use version 2 (Gas Lighter) of the UbiLighter. Each participant was asked to use the lighter exclusively for 4 days and could afterwards decide to continue its usage. All were aware that their cigarette consumption is being monitored by informing them at the onset of the study that the lighter is logging when it is being used and by providing feedback of the prototype working through the indication LEDs during operation.

Number of study participants	11
Average age of participants (in years)	34.53 ± 12.14
Number of (reported) cigarettes per day	15.11 ± 5.95
Average years of cigarette consumption	13.03 ± 6.54
Average days of participation	11.36 ± 8.15

Table 1: Summary of the study participants' smoking habits.

Pre- (Table 3) and post-study surveys (Table 4) were conducted to elicit an estimate of the smoker's cigarette consumption awareness and a subjective opinion of the overall system. The questionnaires contain a number of statements that smokers were asked to grade along a 5-level Likert scale on agreement (agree strongly, agree,

agree somewhat, disagree or strongly disagree). Results in Table 3 and Table 4 are the normalized mean and standard deviation of those assessments. Participants did not access their recordings during the course of the study, but were exposed to a statistical summary (see Figure 1) before answering the post-questionnaire. The gathered data provides the basis of the following findings below.

Results

One of the basic metrics of cigarette consumption is the total number of smoked cigarettes over the course of a day. A comparison of this self-reported and measured number of smoking incidents is given in Table 2. The self-reported number of incidents was extrapolated by multiplying the self-reported daily consumption by the timespan of participation. It is a dominant trend that the participants overestimated their daily consumption compared to the number of measured incidents. This can be attributed to a number of different factors: First of all, the gathering process might not always have worked reliably and some incidents might have been missed. This effect is also visible in the post-study questionnaire results (question 10, Table 2), hinting towards an unreliability of some prototypes. While the lighters needed regular maintenance during the study, this effect should be especially strong for those with short participation time. However, there are participants (number 0 and 7) which are quite near to their estimation and the estimation difference also varies from large to small differences for other participants. It is therefore more likely that smokers find it hard to estimate their average daily consumption.

Since we compared the daily average of consumed cigarettes as measured by the lighter to the extrapolation of single estimate, there is also another explanation. The strong difference of consumed cigarettes might stem from an unawareness of daily variances in behaviour, these variances are captured by the lighters but not by the extrapolation of the single self-report average consumption. To gain a deeper insight into this effect, we distributed the self-report measure over three times of the day (morning, midday and evening) by weighting the total number of cigarettes with the help of the questionnaire results (Table 3). Morning is attributed to question 4,6 and 9, midday to question 2, and evening to question 1,3,16 and 20. Smoking incidents measured by the lighter are attributed to same time-of-days and averaged out over the participation time. This results in an estimated and measured average consumption number on time-per-day basis and can be seen in Table 2. The maxima of the measured per time-of-day consumption are highlighted in bold, while the maxima of the estimated consumption are in italic. Furthermore, the mean and standard deviation of the normalized absolute difference are depicted as well.

This difference represents a comparison of the data gathered through the questionnaire and by the UbiLighter. Standard deviation accounts for the fit of measured time-of-day consumption to the estimated one. The smaller the standard deviation the more cigarettes have been smoked at the time-of-day extracted from the questionnaire. The mean value of this difference depicts the fluctuation of daily consumption, i.e. a larger mean value signifies more deviations from the estimated daily consumption on day-to-day basis, which presents another reason why smokers might find it hard to estimate their daily consumption. Taking another look at the table one can see that participant 7 and 4 do have a good idea about their time-of-day consumption. Overall, it emerged that participants found it hard to gauge their average daily consumption and the usual times when they are smoking.

	number of incidents		Morning		Afternoon		Evening		normalized	
	estimated	measured	estimated	measured	estimated	measured	estimated	measured	mean/std.dev.	daily recurrence
0 (4 days)	36	28	2.10	0.50	*3.90*	**4.00**	2.95	2.50		
1 (27 days)	324	227	1.78	2.89	1.78	**3.81**	*8.45*	1.70		
2 (13 days)	260	88	*9.05*	1.54	9.05	**3.69**	6.79	1.54		
3 (26 days)	312	173	*4.36*	2.58	4.36	**3.19**	3.27	0.88		
4 (14 days)	77	50	1.15	0.57	2.09	**1.71**	*2.26*	1.21		
5 (12 days)	228	85	4.39	2.17	*7.54*	**4.25**	7.07	0.67		
6 (6 days)	120	54	7.58	1.00	2.07	1.50	*10.35*	**6.50**		
7 (4 days)	48	46	*6.30*	3.50	4.64	**5.25**	4.64	2.75		
8 (4 days)	80	11	*7.10*	0.25	7.10	**2.50**	5.68	0.00		
9 (3 days)	60	31	*7.61*	2.33	5.07	**6.00**	7.32	2.00		
10 (12 days)	180	72	4.57	0.08	*6.52*	**3.67**	3.91	2.25		

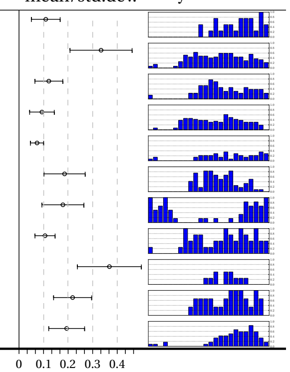

Table 2: Estimated and measured (via the UbiLighter) cigarette consumption figures for all participants. Time of day (Morning, Afternoon, Evening) has been extracted from the pre-study questionnaire (Table 3). The standard deviation of the absolute difference between normalized (over total per-participant cigarette consumption) estimated and measured consumption shows that only some users were able to estimate their main consumption time of the day. The plots to the right show the daily smoking patterns per user.

Another important aspect visible in the recorded data is daily recurrent patterns, i.e., the likeliness of a smoking incident given a specific hour of the day. The daily recurrences for each participants can be found in Table 2. The figure depicts the normalized histogram over 24 hours throughout the course of the study, where each bar represents one hour, for single smoking incidents. It is apparent that, besides the night-time, there is no fixed cross-participant distribution and that the precision of this measure likely depends on the time of participation. However, the time-of-day where a participant is most likely to have a cigarette can thus be estimated. For example, participant 3 has consumed a cigarette at 13.00h on 77% of its 13-day long participation. Other similarly strong patterns are visible for other participants as well. This kind of analysis could allow forecasting the times when a participant is most likely to smoke and could serve as the basis for a more exact just-in-time intervention.

Discussion

The strong differences of self-reported and measured total cigarette consumption are quite pronounced. This, as mentioned in the previous section, can partly be attributed to an unawareness or difficulty to estimate one's daily consumption. During the post-study questionnaire we also asked the participants whether the gathered data is matching their real consumption (Table 4 question 10), i.e., if the participants are "trusting" the system, which all participants rated as "applicable" or "somewhat applicable". Apart from the indication LEDs, there was no direct feedback of the recorded data. Participants thus could check whether data were recorded but not what these data looked like. The participants were however also asked to check the report of their daily consumption (see Figure 1) before answering the post-study questionnaire.

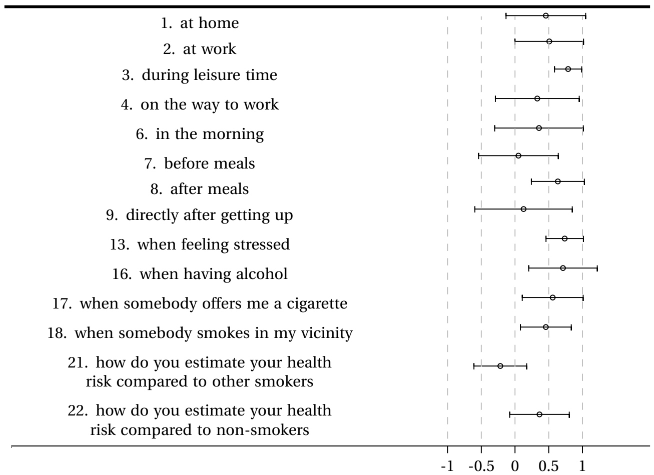

Table 3: Pre-study questionnaire results on smoking self-awareness. Participants graded statements via a five-level likert-scale from "definitely not applicable" (-1) to "strongy applicable" (1). Questions 21 and 22 are of qualitative nature, ranging between "much lower" (-1) to "much higher" (1).

Detecting daily recurrences, in order to forecast smoking incidents, could be improved by taking further contextual data into account. Separating the week into work- and non-work days and calculating the likeliness on these time-spans could improve the accuracy as a lot of participants smoke during work (Table 3 question 2). Additionally using location or activity recognition sensors could give an even more detailed view on the factors that could cause smoking incidents. This finer-grained context information would further improve the users' experiences.

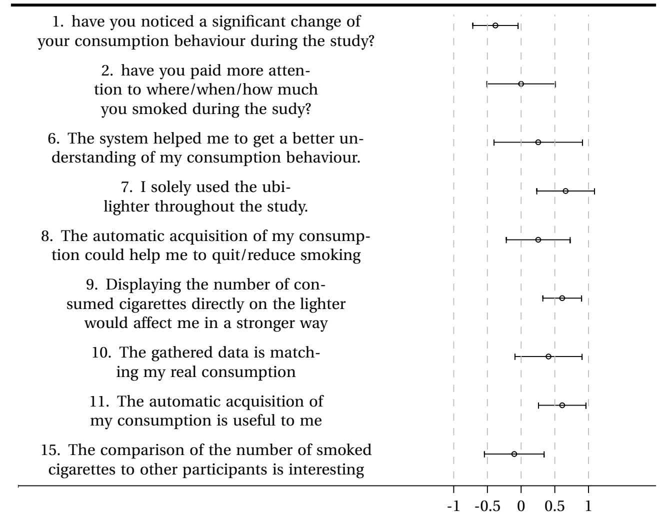

Table 4: Post-study questionnaire results on system usability and participants experience/opinion.

Despite the fact that the UbiLighter v1 (coil based) needed to be recharged often, there were no significant adoption problems. However, the time needed for the coil-based lighter to heat up has been pointed as problematic by some participants. This can be seen in the results of question 7 (Table 4), where participants have been asked if they solely used the provided prototypes.

Furthermore, participants felt that the system helped them to raise their awareness of their smoking behaviour (question 6), could help them to quit (question 8), and deem the automatic acquisition to be useful (question 11).

Conclusions and Future Work

We have presented a prototype that aims at detecting cigarette smoking instances, called the *UbiLighter*. It replaces the traditional cigarette lighter with a prototype that detects its usage and logs the timestamps of these instances in internal memory for later study. We reported on two design iterations for this prototype, where one is using a heating coil to light the cigarette, and the second one is an augmentation of a traditional gas lighter.

A preliminary feasibility study with 11 frequently-smoking users was conducted, in which the participants were asked to use the UbiLighter and gathered data was compared with self-report measures from questionnaires before and after the study. Strong discrepancies between the self-reported total consumption and time-of-day of consumption have been found, which can be attributed to a poor self-awareness of smokers. Furthermore, daily recurrent patterns of smoking incidents can be identified on per-subject basis, which can allow to forecast the time-of-day of smoking incidents and help to create more precise just-in-time and improved interventions in order to help users to gain more control through an unbiased, objective and effortless feedback of their consumption.

To increase the user's trust in the system future work should concentrate on allowing for direct feedback from the measurement system. This could be achieved by adding a display or wireless capabilities to the UbiLighter. Such a system would allow to intervene when smoking incidents happen and affect its users in a strong way.

Acknowledgements

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References

[1] Ali, A. A., Hossain, S. M., Hovsepian, K., Plarre, K., and Kumar, S. mPuff: Automated Detection of Cigarette Smoking Puffs from Respiration Measurements. In *IPSN* (2012), 269–280.

[2] Beard, E., and West, R. Pilot Study of the Use of Personal Carbon Monoxide Monitoring to Achieve Radical Smoking Reduction. *Journal of Smoking Cessation 7*, 01 (July 2012), 12–17.

[3] Brown, J., Michie, S., Geraghty, A. W. a., Miller, S., Yardley, L., Gardner, B., Shahab, L., Stapleton, J. a., and West, R. A pilot study of StopAdvisor: a theory-based interactive internet-based smoking cessation intervention aimed across the social spectrum. *Addictive behaviors 37*, 12 (Dec. 2012), 1365–70.

[4] Fletcher, R. R., Tam, S., Omojola, O., Redemske, R., and Kwan, J. Wearable sensor platform and mobile application for use in cognitive behavioral therapy for drug addiction and PTSD. *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference 2011* (Jan. 2011), 1802–5.

[5] Fogg, B. J. Persuasive technology: using computers to change what we think and do. *Ubiquity 2002*, December (2002), 5.

[6] Jarvis, A., Vincze, M. P., Falconer, B., Garde, A., Geber, F., and Daynard, R. A Study On Liability And The Health Costs Of Smoking, 2009.

[7] Klasnja, P., and Pratt, W. Healthcare in the pocket: mapping the space of mobile-phone health interventions. *Journal of biomedical informatics 45*, 1 (Feb. 2012), 184–98.

[8] Li, I., Dey, A. K., and Forlizzi, J. Understanding My Data, Myself: Supporting Self-Reflection with Ubicomp Technologies. *Discovery* (2011).

[9] Lopez-Meyer, P., Tiffany, S., Yogendra, P., and Sazonov, E. Monitoring of cigarette smoking using wearable sensors and Support Vector Machines. *IEEE transactions on bio-medical engineering*, c (Jan. 2013).

[10] Nakajima, T., Lehdonvirta, V., Tokunaga, E., and Kimura, H. Reflecting human behavior to motivate desirable lifestyle. In *Proceedings of the 7th ACM conference on Designing interactive systems*, ACM (2008), 405–414.

[11] Organization, W. H. Mortality country fact sheet, 30 May 2006.

[12] Rodgers, a., Corbett, T., Bramley, D., Riddell, T., Wills, M., Lin, R.-B., and Jones, M. Do u smoke after txt? Results of a randomised trial of smoking cessation using mobile phone text messaging. *Tobacco control 14*, 4 (Aug. 2005), 255–61.

[13] Sazonov, E., Metcalfe, K., Lopez-Meyer, P., and Tiffany, S. RF hand gesture sensor for monitoring of cigarette smoking. In *Sensing Technology (ICST), 2011 Fifth International Conference on*, IEEE (2011), 426–430.

[14] Scholl, P. M., and Laerhoven, K. V. A Feasibility Study of Wrist-Worn Accelerometer Based Detection of Smoking Habits. In *International Workshop on Extending Seamlessly to the Internet of Things2* (2012).

[15] Science, B. Bedfont science - smokerlyzer.

[16] Shahab, L., and McEwen, A. Online support for smoking cessation: a systematic review of the literature. *Addiction (Abingdon, England) 104*, 11 (Nov. 2009), 1792–804.

[17] Society, A. C. Cancer Facts & Figures, 2012.

[18] Velicer, W. F., Prochaska, J. O., and Redding, C. a. Tailored communications for smoking cessation: past successes and future directions. *Drug and alcohol review 25*, 1 (Jan. 2006), 49–57.

[19] Wu, P., Hsieh, J.-w., Cheng, J.-c., Cheng, S.-c., and Tseng, S.-y. Human Smoking Event Detection Using Visual Interaction Clues. In *Pattern Recognition (ICPR), 2010 20th International Conference on* (2010).