Lessons Learned From Designing an Instrumented Lighter for Assessing Smoking Status

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Abstract
Assessing smoking status from wearable sensors can potentially create novel cessation therapies for the global smoking epidemic, without requiring users to regularly fill in questionnaires to obtain their smoking data. In this paper we discuss several design iterations of an instrumented cigarette lighter the records when it is used, to provide the ground-truth for detection from sensor signals measured at the human body, or to provide an alternative low-delay detection mechanism for smoking.

Author Keywords
Smoking Cessation; Hardware Design; Data Collection

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Introduction
Twenty-two percent of the global population older than fifteen are consuming at least one cigarette per day [1]. And even though the percentage of daily smokers has decreased by roughly 30% in the last decades, the gross number of smokers [2] increased to a total of 967 millions due to steady population growth. In Europe, for instance, 27% of all citizens are still regular smokers, especially in

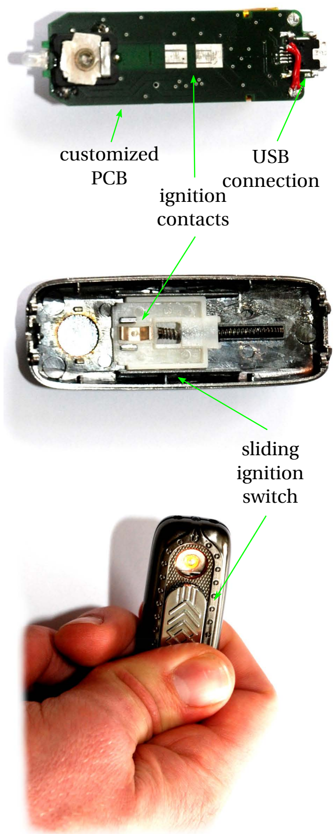

Figure 1: The UbiLighter v.1's internal buildup. Top, a mechanical switch closes the circuit between battery and a coil, allowing it to heat up so that a cigarette can be lit up. The time of ignition is logged by an on-board micro-controller that is connected to a real-time clock.

age groups below 55. Around 59% tried to quit at least once [3], often motivated by fear of personal health consequences. This is understandable as continued smoking has been most prominently linked to cancer forms of highest mortality rate, as well as other diseases causing premature death [4]. The resulting economic loss, both due to absenteeism in the workforce, as well as the cost for treating tobacco-related diseases was estimated to about €313 billion [5] in the EU and $191 billion in the US [6].

We designed a lighter to capture reliable ground truth for an objective assesement of the smoking status by motion recorded from wearable sensors. To be objective, an assessment should be inconspicuous, accurate and efficient (inconspicuous, so participants are not aware of them being tracked, as to not alter their behaviour). At the same time this assessment should reflect the real events as close as possible, since otherwise important details could be missed, or wrong conclusions drawn. Resources, such as a participant's involvement, available battery and processing power should be minimized to allow for a longitudinal assessment. This is particularly challenging for smoking, because current approaches either ask for noting down times on paper, tracing bio-chemical nicotine markers [7], interacting with a mobile device, or wearing devices that might usually not be worn or at uncomfortable locations. During the design phase, we followed the guidelines layed out by Li et.al., 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 result of this were several iterations of the *UbiLigher*, which logs its usage into the internal memory of a microcontroller. The UbiLighter's iterations became more usable, communication capabilities were added, and they were easier to manufacture.

Instead of relying on the discipline of a study participant to provide an ecological momentary assessment (EMA), we trivialise the detection of smoking events. Both from a technical and conceptual aspect, to make sure that detections are as reliable and efficient as possible. With those detected smoking events, new insights into smoking cessation can be gathered. For example, the efficacy or impact of smoking cessation programs is currently measured with the abstinence rate after 3-, 6- and 12-month periods. These number are commonly gathered via telephone interviews, adding delay and uncertainties. With an ambulatory assessment, with any of the above techniques, these number can get a lot finer. This in turn could provide new insights into the efficacy of cessation tools, like nicotine patches or personal counseling. Novel cessation approaches are another possibility. Intervention material can be (automatically) personalized, interventions can be provided just-in-time, novel insight generated for the smokers or cessation material directly tested on its usefulness.

Lighter Prototypes

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. Tracking itself becomes trivial, and thus provides a more reliable solution. Implementing such a device is however aggravated by the availability of lighters that generate a measurable electronic signal when used. Currently, there are four lighter types widely used: gas, petrol, electric arc and electric coil lighters. Coil lighters, similar to the ones found in cars, work by closing an electronic circuit which heats up a coil with a large current[1]. Arc lighters work by generating a plasma between two electrodes. Both electronic lighter are usually

[1] See Joule Heating for details.

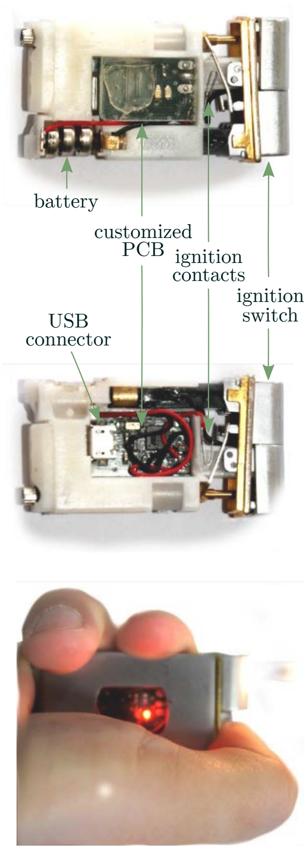

Figure 2: The UbiLighter v.2's internal buildup. The ignition contacts additionally close a circuit, which is read by the micro-controller. On the top the battery compartment and LEDs are visible.

powered by a USB re-chargeable battery. Gas and petrol, on the other hand, store the required energy in a some flammable, evaporating fuel. A spark generated by some mechanical force ignites this fuel. Commonly, this spark is generated by scratching a flint stone or by a high voltage discharge of a compressible piezo element. These constitute the basic working principles from which a measurement mechanism must be deduced.

Each prototype logs the date and time of each ignition, which results in a list of events that are likely related to cigarette smoking, especially if the user was properly instructed on the lighter's use. Multiple ignitions in quick succession are filtered, assuming that only a single cigarette will be consumed in a five minute interval. All prototypes measure those events, and differ mostly in usability and communication capabilities. The lighters are described in the following sections.

UbiLighter v1: Heating Coil
Initially, the PCB of an electronic lighter (cf. fig. 1) was replaced to include an ATMega32U2 micro-controller and an external real-time clock (RTC). An internal 200mA h battery provides power for heating up the coil, and the micro-controller. Events were logged into internal memory and could be retrieved via USB - they are detected by monitoring the state of the ignition contacts. Closing these contacts wakes up the micro-controller and ignites the lighter. The components were packed into the original lighter casing to provide a prototype that is robust enough for day-to-day usage.

The firmware is designed to consume as little power as possible; During periods of no activity the micro-controller is in deep sleep mode and only wakes up on USB activity or when the switch contacts change their state. Only the RTC is constantly drawing power, which leads to an overall standby power consumption of $0.04\mu\text{A}$. Whenever the switch is moved, the micro-controller wakes up from sleep, reads the current time from the RTC and appends the time-stamp to a list in flash memory. Each timestamp takes up 4B, which allows to store up to 255 events in the 1kB sized internal memory of the microcontroller.

Although this first prototype was found to work well in preliminary trials (see [9]), several shortcomings were found that hinder more extensive deployments. 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. Due to this, cigarettes were harder to light up, as the coil needed at least five seconds to heat up. When the battery provides its nominal voltage, after it was discharged to about 70% of its initial capacity, this took even longer. The lighter was also harder to use, since it requires careful aiming of the cigarette onto the heating coil, and if the coil was not yet hot enough the cigarette would break. 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 ($\sim 15\frac{cigs}{day}$) before it needs to be recharged, which bothered several users.

UbiLighter v2: Gas
Despite having a very different form factor, the PCB for the second version of the *UbiLighter* contains essentially the same electrical components. The ATMega32U2 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 (see Figure 2). Together with a external real-time clock (RTC), a USB port and two status LEDs, the logging of

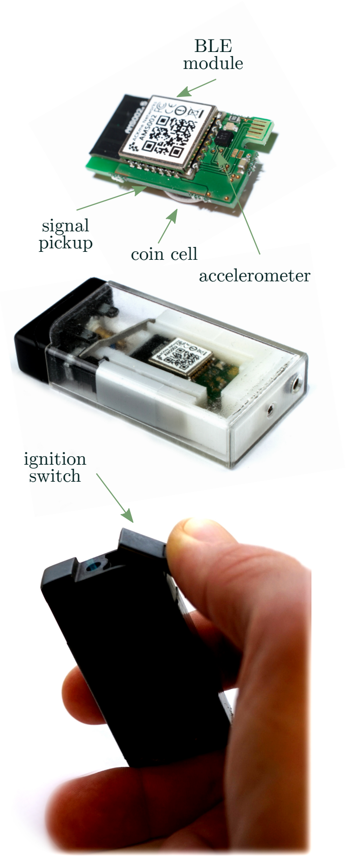

Figure 3: v.3's interal build. Contact-less ignition detection is achieved by monitoring for a high-voltage spark generated by piezo ignition. A Bluetooth Low Energy (BLE) module communicates events directly to connected Smartphones.

smoking instances is performed. The 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 30mA h of power. The cells can continuously power the lighter for about 20d at frequent usage ($\sim 15\frac{cigs}{day}$). This ten-fold increase of runtime, while decreasing the available power ten-fold, is mostly due to the use of a combustible fuel for providing a flame to light cigarettes.

The process of capturing and recording the smoking instances is for the second version similar to that of the first, if there has been no write operation during the last 5min the timestamp is written into the internal non-volatile memory of the micro-controller. The 5min 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 5min interval has been chosen as the mean time to consume a cigarette[10][2]. The smoking incidents timestamps can be downloaded from the lighter via a virtual serial port emulated by the Atmega32U2 in `CSV`-format through the USB-port.

While the novel form factor meant that no adaption of the smokers behavior was required, it had several practical issues. First of all, the USB port was 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 - no real-time feedback was possible. Due to the mechanical connection to the lighter this process often required to repair the lighter afterwards. To remedy this situation, optical transmission from the included lighter to unmodified cameras in commodity hardware was investigated [11].

Further design choices considered for this iteration of the UbiLighter included the modification of Zippo lighters. Temperature or contact sensors and batteries could be added. However 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 tough. The only way to attach them is either in the compartment holding the flammable fluid or on the case's outside.

UbiLighter v3: Piezo Ignited

Due to the mechanical instability of prototype v.2 another detection mechanism was devised, which improves the lighter's manufacturability. Instead of relying on a mechanical switch connected to a micro-controller pin, the ignition is now picked without any contact. Common lighters use a piezo ignition. Compressing the piezo element inside this ignition results in a high-voltage spark, which is used to light up flammable fuel. A large cooper area in the vicinity (cf. fig. 3) of this ignition connected to a pulled-down micro-controller pin will pick-up a voltage above the micro-controller's logic level. This can be used to wake the micro-controller whenever the lighter is ignited. By carefully controlling the size of this area, no external electrostatic discharges (ESD) are picked up. This way, the manufacturing process is limited to just placing the module near the piezo ignition.

Another novelty of this prototype is the addition of BLE to communicate with nearby Smartphones. Introduced in 2015 it was the first wireless communication standard

[2]The systematic review investigated smoking topography studies with a total volume of $n = 193$ participants, which reported $17.23 \pm 6.88\frac{cigs}{day}$, with an inter-puff delay of $15.46\pm7.18\text{s}$, and puff duration of $2.32 \pm 3.3\text{s}$ (Method 1). The total consumption time can be sampled to $306.75 \pm 129.01\text{s}$.

which was power-efficient enough to be run from a coin cell and was pervasively included in Smartphones. The timestamps of ignition are now not just stored in local memory, but also communicated to nearby phones in real-time. Just-in-time intervention are now possible, and sensor recordings on other devices and external computations can be triggered directly. Once timestamp have been retrieved from the lighter, they are deleted from local memory. Communication is limited to two minutes after an ignition to conserve power. If no communication partner was in reach during this period, the event will be communicated together with the next ignition event. Thus creating a robust, reliable and real-time monitoring system, which can be powered for 3 months from a single 48mA h coin cell. The system is packaged in a re-purposed gas jet lighter, which originally included a decorative block of acryl where the electronics reside now.

Lessons Learned

Looking at the design decisions for the several prototypes in retrospect, the following design principles would have possibly provided *faster*, and more *mature* results:

Optimize for original purpose first. While the initial prototype provided first insights into the hardware choices required for including electronics into a readily available lighter, the lighter itself was not well designed for its primary usage. From the perspective of collecting smoking data (our intended usage), starting from an existing lighter was a very good choice as it included a battery and a USB connection already, so only minimal modifications were necessary. Its primary use for lighting cigarettes with a heated coil, however, was often challenging for smokers. During its study use, smokers often reported to use the instrumented lighter for logging, next to a traditional lighter for actually lighting up the cigarette.

Design for robustness of everyday objects. The second prototype had to be opened up to retrieve the logged smoking events. In principle this created a one-time usage device, as the reassembly after data retrieval was almost the same as assembling a lighter from scratch. This was partially due the measurement principle, which required fragile, internal wiring that would often break. Contact-less data transmission, as with the third prototype, would have solved this issue early on.

Render tangible and immediate interactions. All prototypes had LEDs on them, to display the lighter's internal status. This interaction, however, was fairly limited and feedback from early adopters often revolved around the point that they could get immediate insights of their measured smoking behaviour. For the first two prototypes such feedback was only given when they visited us again so that we could retrieve data from the lighter - while this allowed for inconspicuous monitoring, it also made the idea for the smoker less transparent.

Conclusion

We presented in this paper several versions of the UbiLighter, an augmented cigarette lighter that users can carry along and which implicitly captures and collects smoking instances when used. The lessons learned from the UbiLighter might inform other design, in which everyday objects are instrumented with a usage detect mechanism, and whose data are then digitally communicated to other services. In our research, the major challenges to overcome were not to *not hinder the original purpose of the object*, design for *high maintainability* and *power efficiency*, and to provide *adequate communication capabilities*.

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