Retrofitting Smartphones to be Used as Particulate Matter Dosimeters

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ABSTRACT
This work discusses ways of measuring particulate matter with mobile devices. Solutions using a dedicated sensor device are presented along with a novel method of retrofitting a sensor to a camera phone without need for electrical modifications. Instead, the flash and camera of the phone are used as light source and receptor of an optical dust sensor respectively. Experiments to evaluate the accuracy are presented.

Author Keywords
Retrofitting, Camera Phones, Particulate Matter, Dust Sensing, Air Quality, Personal Health, Participatory Sensing.

ACM Classification Keywords
B.4.m Input / Output and Data Communiations: Misc.

General Terms
Design; Experimentation; Human Factors; Measurement

INTRODUCTION AND RELATED WORK
Past studies have shown that exposure to fine dust can pose a serious health hazard. Beyond omnipresent sources of particulate matter (PM), e.g. traffic, risks can also occur at home or in a working environment. A good example are laser printers, the fine toner dust from which can even result in permanent disability if inhaled over years [6]. Additionally, people may have a higher than usual susceptibility or exposure to fine dust, for instance woodworkers or coalminers. Inexpensive handheld measurement could enable *personal exposure monitoring*, *hotspot detection* or large scale *participatory sensing*. However, handheld fine dust monitoring currently requires expensive dedicated devices. The cost of commercial monitors is in the range of one to several thousand dollars. Other devices in principle offer personal exposure monitoring: [5] presents a sensor node for indoor PM sensing, unfortunately without details on the sensor itself. The gravimetric measurement approach of the small, wearable *Personal Environmental Monitor (PEM)* [9] makes the evaluation of the collected samples cumbersome. In [2], the suitability of several small, low-cost sensors for mobile fine particle measurements is discussed, and the *Sharp GP2Y1010* sensor is identified as most appropriate. As an alternative to dedicated measurement devices we propose to retrofit smartphones with an exchangeable dust sensor embedded into the back shell (Figure 1). Other work has shown that a phone's camera and flash can be leveraged beyond taking photos, e.g. to measure physiological parameters [4], such as the heart rate [8].

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SYSTEM DESIGN AND EXPERIMENTS
We conducted experiments with a special platform [3, 1] that incorporates the *Sharp GP2Y1010* dust sensor. Its measurement principle is the same as that of most optical dust sensors: light is emitted into a measurement area. When dust is present, the emitted light is scattered. A transfer function between the amount of refracted light and the aerosol dust concentration enables measurement of the dust levels. After calibration of the sensor and dealing with several other difficulties, such as sensor drift and changing offsets, comparisons to a gauged reference device deliver very promising results (Figure 2). While this shows that mobile particulate matter sensing of very low concentrations is possible using commodity dust sensors, the employed sensors are not yet embeddable into phones. Instead, they need to be incorporated into external platforms that communicate their measurements to a host via USB or Bluetooth. A drawback of this approach is that

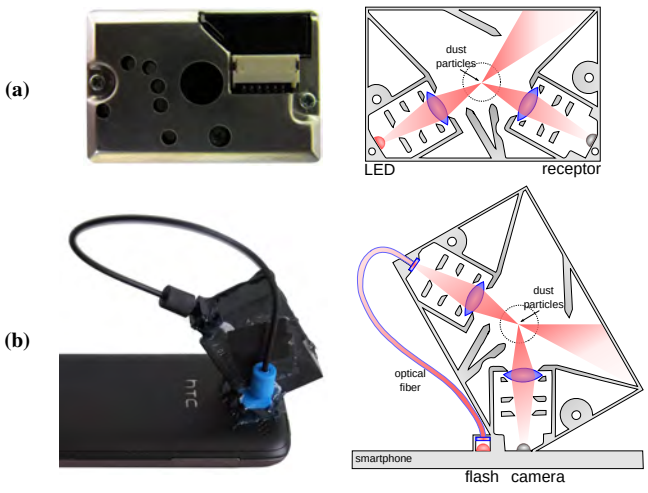

Figure 1. (a) Sharp GP2Y1010 dust sensor and operation principle, and (b) prototypical implementation with modified emitter-receptor configuration embedded in the back shell of an otherwise unaltered phone.

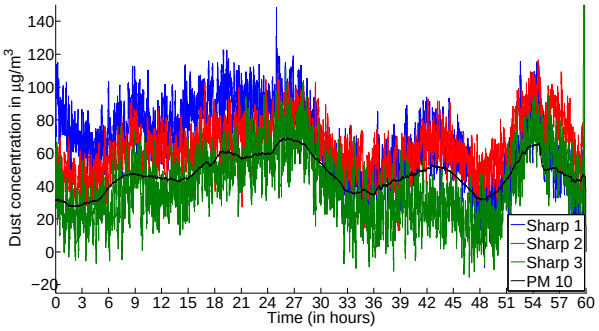

Figure 2. Indoor PM_{10} concentration measured with a calibrated *Sharp GP2Y1010* dust sensor. Accuracy is in the µg/m³ range.

additional costs arise for a microcontroller platform that controls the sensor and transmits the data. Another option is to directly connect an analog sensor to a phone, e.g. using the headphone jack [7]. However, the *GP2Y1010* is not a regular analog three-wire-sensor: Its LED is pulsed, i.e. there is an additional circuit powering the emitter that needs to be enabled and disabled according to precise timing specifications, which makes this approach difficult. The proposed alternative – modifying the back shell of an off-the-shelf smartphone – has several advantages: There is no embedded electronics involved, making the design cheaper. Also, the sensor is very easy to install and can be exchanged again for a regular back shell when it is not needed.

For our modifications, we used an unaltered *HTC Desire* smartphone running *Android 2.3.3*. We attached a disassembled *Sharp GP2Y1010* dust sensor's light trap and lenses to the back cover of the smartphone. This was done such that the phone's camera replaces the original photodiode. A short piece of optical fiber was then used to convey the light from the phone's LED flash to the correct position of the light trap, replacing the sensor's original LED (Figure 1b). Both components were optically isolated from each other. An application records a series of still images or video frames for the duration of the measurement. The captured images are then analyzed and the light intensity is translated to a concentration level. We tried several metrics and compared our prototype against a gauged reference device, a *TSI DustTrak DRX 8533* aerosol monitor. As transfer function, first a grayscale histogram of the image is built and then the amount of pixels n_i for each of the 256 intensity levels i is counted. The output is the weighted sum $\Sigma_{i=0}^{255} = i \cdot n_i$, thus giving each pixel a weight correlating to its intensity. Figure 3 and Figure 4 show that the readings correspond very well to those of our reference device, down to concentration levels of ~10 mg/m³. While this is enough to detect smoke or coarser dust, it is not yet sufficient for the detection of typical fine dust concentrations. We suspect that the cause of this that the coupling between flash and optical fiber is not optimal in our prototype, leading to insufficient light intensity levels.

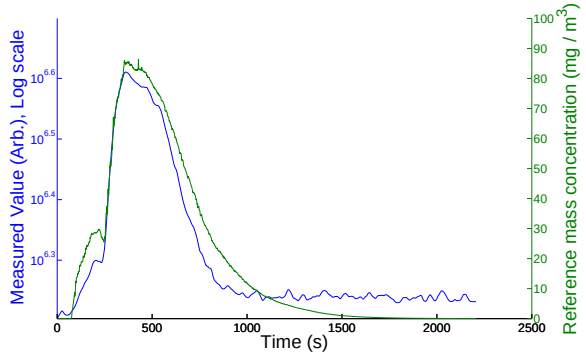

Figure 3. Example particulate matter concentration measured with our first prototype, producing accurate readings down to ~10 mg/m³.

CONCLUSION AND FUTURE WORK

We have shown a novel approach to retrofit camera phones with dust sensing capabilities. The presented design was tested and shows good initial performance. As future work, we aim to increase the sensitivity to detect much lower concentrations. To this end, we are currently working on a better coupling of the LED and the optical fiber. Another important aspect is to improve the form factor of the sensor to be less bulky. We will asses to which degree miniaturization is possible through a light trap design of our own. Additionally, the orientation of the sensor might be adjusted by improving the optical path, so that the sensor does not jut out so much.

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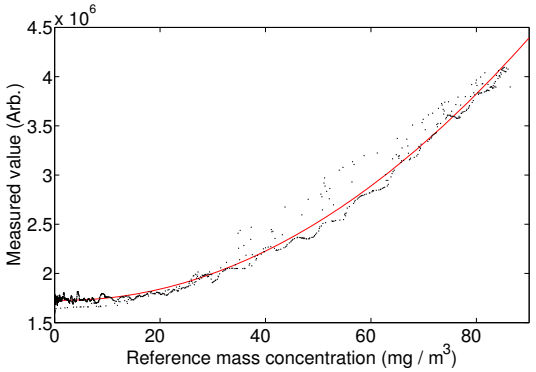

Figure 4. Output values of our prototypical smartphone dosimeter vs. those of the reference device *TSI DustTrak DRX 8533*.