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Comparing methods for signal analysis of temperature readings from stove use monitors

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ABSTRACT

Understanding the daily use patterns of traditional and nontraditional cooking technologies is essential for researchers and policy makers attempting to reduce indoor air pollution and environmental degradation from inefficient cookstoves. This paper describes field methods and proposes a new algorithm for converting temperature data generated from stove use monitors into usage metrics for both traditional and nontraditional stoves. Central to our technique is recording the visual on/off status of a stove anytime research staff observes the stove. The observations are regressed against temperature readings in a logistic regression to estimate the probability that a temperature reading indicates usage. Using this algorithm we correctly predict 89% of three stone fire observations and 94% of Envirofit observations. The logistic regression correctly classifies more observations than published temperature analysis algorithms. This is the first published algorithm for converting temperature data for traditional stoves such as three stone fires.

1. Introduction

This study examines how best to measure the use of nontraditional and traditional stoves, an important step in the effort to mitigate the harm caused by inefficient cookstove designs. Traditional wood-and charcoal-burning stoves both burn inefficiently and produce a great amount of smoke. The smoke leads to respiratory, heart, and other disorders that kill approximately four million people per year [1]. Much of the health burden is concentrated on women and children, as is the time burden collecting biomass fuel [2]. Environmental damage can be significant; by one estimate, household energy use in Africa will produce 6.7 Gt of carbon by 2050 [3]. Furthermore, the incomplete combustion of biomass fuels leads to the release of black carbon (soot) that contributes to current global warming [4,5]. These inefficiencies imply deeper poverty, loss of biodiversity, rapid deforestation, and climate change. These problems have led both policy-makers and practitioners to search for safer and more fuel-efficient stoves that are attractive to consumers as substitutes for traditional stoves.

One challenge to understanding stove use substitution behaviors is to measure stove use precisely, economically and with minimal intrusion into the lives of study participants. Measuring stove usage with minimal observation bias is

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necessary to recover unbiased estimates of stove use because study participants behave differently when research staff are present [6] and because study participants over report stove use when it is self-reported [7]. Scientists studying the health effects of cooking technologies need to understand how many hours a day a stove is used to estimate exposure to household air pollution [8,9]. Project financiers need to measure the time cooked on both new and old stoves to allocate the carbon credits that can fund stove subsidies in developing countries [10–12]. Further, "stove stacking" (the use of multiple fuels and stoves) often occurs when multiple cooking options exist [13–15]. To understand any of these issues researchers must know the baseline amount of cooking on existing stoves, and then the time cooked on both the existing and new stove.

Pioneering stove studies have highlighted the harmful effects of indoor air pollution and the health benefits of adopting fuel-efficient nontraditional stoves [16–22]. However these studies were characterized by high levels of interactions between research staff and study participants; for example, in Ref. [16] research staff noted the locations of each household member and the status of how active the cooking fire is every 5–10 min. Observational studies of stove use raise the possibility of observation bias (or Hawthorne effect), which arises when participants act differently than they normally would because they know they are being observed (as noted by Ref. [22]). Our study is similar to [7] in that both use co-located observational and sensor data to calibrate a sensor to measure household product use (in their case, a water filter).

To minimize observation bias, stove use monitor systems (SUMs) can record stove temperatures without the need for an observer to be present. The SUMs used for our project, iButtons™ manufactured by Maxim Integrated Products, Inc., are small stainless steel temperature sensors about the size of a small coin and the thickness of a watch battery that can be affixed to any stove type. The SUMs used in our study record temperatures with an accuracy of ±1.3 °C up to 85 °C (see Fig. 1 for a photograph). Stove Usage Monitors that log stove temperatures were first suggested by Ref. [23]. SUMs offer an unobtrusive, precise, relatively inexpensive (approximately USD $16 each), and objective measure of stove usage [23,24].

We know of two published algorithms for determining stove usage with SUMs. Both studies use SUMs to measure the temperature of nontraditional cookstoves at set time intervals, and then calculate temperature changes between readings. In Ref. [25] the algorithm considers an increase in temperature above a certain threshold (1.52 °C increase over 40 min) as the start of a candidate cooking or refueling event. If the post-increase stove temperature is also above the ambient temperature, the algorithm counts the passage of time until a temperature drop indicates that the stove is cooling down (indicated by a 2.28 °C decrease over 60 min), signaling the end of the cooking event. These slope thresholds are chosen by taking the 99th and 1st percentiles of slope values from the distribution of ambient air temperatures in the research area. Multiple temperature peaks within a 2 h period of each other are considered the same cooking event [25]. A similar technique, combining both change in slope and a temperature threshold to classify when a stove is being used, is used in a similar study, however, the researchers choose different thresholds based on observed local cooking practices and local ambient temperatures [26].

The use of temperature slopes to identify cooking works well for heat-efficient manufactured stoves, such as those used in these two studies [25,26]. Because these stoves heat and cool quickly and have fixed form-factors, temperature slopes are steep and can be consistently measured by SUMs attached to a fixed spot. For traditional stoves, such as a three stone fire, however, the use of temperature slopes can be challenging for two reasons. First, three stone fires heat and cool more slowly, producing more attenuated temperature slopes. Second, each three stone fire has a unique form-factor that can change over time, e.g., a stone is moved. Thus, the same cooking activity could create different measured temperature slopes both across stoves and within the same stove over time. The challenges suggest that a more flexible functional form mapping temperature readings to cooking activities might be advantageous for three stone fires.

We propose a methodology that uses SUMs temperature data gathered in the same way as previous studies, but combines this temperature data with observations made throughout the experiment of when stoves were seen as on or off. We run a logistic regression that fits SUMs temperature data to observations of stoves being on or off. We then take the coefficients from this regression to predict the probability of cooking over the much larger set of SUMs temperature readings without any observational data. The researcher can sum the predicted minutes cooked in a 24-h period to estimate minutes of cooking that day. This measure of cooking can then be used as the basis for other analysis such as comparing cooking behaviors between groups of households with certain characteristics or groups differentiated by experimental design.

Fig. 1 – Photograph of stove use monitoring system (SUMs).

2. Methods

Our technique requires continuous SUMs temperature data for a given stove, and recorded instances of whether that particular stove is seen in use or not (henceforth called "observations"). We matched observations of stove use to SUMs temperature data by time and date stamps. The core of our