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Making Sanitation Count: Developing and Testing a Device for Assessing Latrine Use in Low-Income Settings

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ABSTRACT: While efforts are underway to expand latrine coverage to an estimated 2.6 billion people who lack access to improved sanitation, there is evidence that actual use of latrines is suboptimal, limiting the potential health and environmental gains from containment of human excreta. We developed a passive latrine use monitor (PLUM) and compared its ability to measure latrine activity with structured observation. Each PLUM consisted of a passive infrared motion detector, microcontroller, data storage card, and batteries mounted in a small plastic housing that was positioned inside the latrine. During a field trial in Orissa, India, with ~115 households, the number of latrine events measured by the PLUMs was in good agreement with that measured by trained observers during 5 h of structured observation per device per week. A significant finding was that the presence of a human observer was associated with a statistically significant increase in the number of latrine events, i.e., the users modified their behavior in response to the observer. Another advantage of the PLUM was the ability to measure activity continuously for an entire week. A shortcoming of the PLUM was the inability to separate latrine events that occurred in immediate succession, leading to possible undercounting during high-traffic periods. The PLUM is a promising technology that can provide detailed measures of latrine use to improve the understanding of sanitation behaviors and how to modify them and for assessing the intended health, livelihood, and environmental benefits of improved sanitation.

INTRODUCTION

Background. An estimated 2.6 billion people lack access to improved facilities for the disposal of human excreta, such as a basic pit latrine.[1] One billion people, including an estimated 638 million in India alone, still practice open defecation. Seven out of ten people who are without improved sanitation live in rural areas. Projections indicate that current progress will fall more than 1.7 billion short of meeting the Millennium Development Goal sanitation target to half the portion of the population without access to improved sanitation by 2015.[1]

Faced with this challenge, governments, nongovernmental organizations (NGOs), and others are redoubling efforts to expand sanitation coverage. In India and several other countries, initiatives are driven by government subsidies that reimburse householders for much of the cost of construction.[2] Large-scale sanitation campaigns driven by government subsidies report impressive gains in latrine coverage but low levels of use.[3,4] In a recent assessment of a 5-year water, sanitation, and hygiene promotion program in the southern Indian state of Tamil Nadu, investigators reported a substantial increase in latrine coverage, from 15% to 48%; however, even among households that had built a latrine, 39% of adults and 52% of children were reported to continue the practice of open defecation.[5]

Perhaps because it is easier to deliver and count hardware than change and measure behavior, public health interventions are often assessed on the basis of coverage rather than actual uptake. However, the assumption that building latrines alone is effective in minimizing exposure from unsafe disposal of human faeces is especially problematic. First, unlike interventions such as improved water supplies that are often immediately embraced by the target population, moving a population from open defecation to the use of latrines often requires fundamental changes in deeply held, culturally driven behaviors.[6] Second, even a comparatively small number of nonusers can contaminate the environment with fecal pathogens, jeopardizing the potential health gains from improved sanitation.[7]

The importance of distinguishing between latrine coverage and latrine use in terms of health outcomes has been

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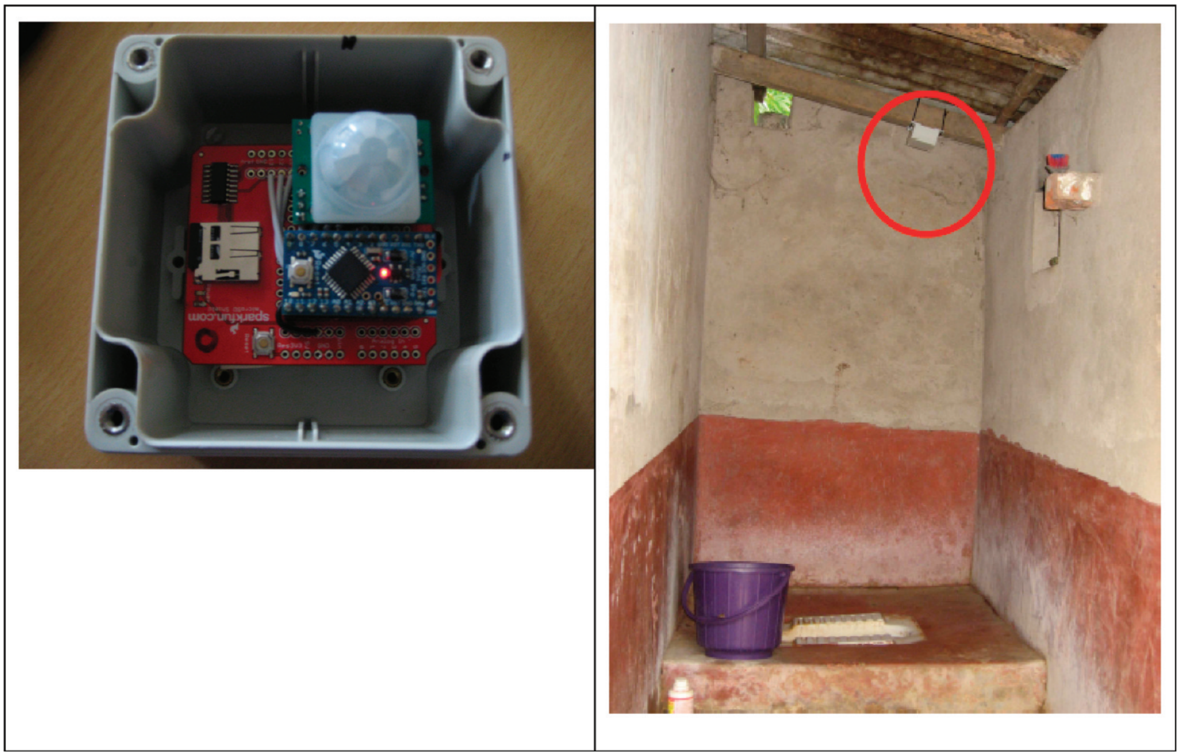

Figure 1. The PLUM device with cover removed (left); typical installation at the study site, Orissa, India (right).

demonstrated for trachoma, the leading cause of preventable blinding.[4,8] Montgomery and colleagues[4] reported that, in seven studies where latrine *ownership* was assessed, no clear relationship was found with active trachoma; however, in four studies of latrine *use* compared to open defecation, all found significant associations with decreased risk of trachoma. Thus, to optimize health gains, sanitation campaigns must emphasize use of latrines.

Nevertheless, the current tools for measuring latrine use are inadequate. Structured observation can be incompatible with the private practice of defecation, requires extended time, and can be costly at scale. In addition, a limitation of structured observation documented in handwashing trials is that study participants may alter their behavior in response to the presence of an observer (often termed the "Hawthorne" effect).[9,18] Self-reported latrine use is unreliable; hand washing and other studies have demonstrated that self-reported uptake of behavioral interventions overstates the target behavior due to courtesy and other reporting biases.[10] To the extent that they measure latrine use at all, most studies of sanitation rely on checklists of indicators from inspecting latrines (well-worn path, wet floor, odor, flies, fresh faeces, presence of anal cleansing materials) and sanitary surveys of the area (presence of human faeces in the area).[4,11,12] However, these approaches are subjective and may lack necessary sensitivity and specificity to quantify patterns of use. Looking down into pits for fresh faeces or measuring changes as latrine pits fill with a laser ruler or simple dipstick also lack sensitivity and specificity and are not possible for water-sealed or other latrines where the pits are not accessible. What is needed is a low-cost, acceptable solution that researchers, program implementers, program evaluators, and others can use on different structures and in various settings (households, schools, public latrines) to monitor and motivate latrine use. Unobtrusive electronic devices have been used to measure hand washing with soap,[13,14,18] anal cleansing,[14] and exposure to indoor air pollution.[15]

The goal of this project was to develop and evaluate the performance of a "passive latrine use monitor" (PLUM) device, a sensor system designed specifically for assessing latrine use in low-income settings. We report below on the design of the sensor device, as well as its field evaluation in Orissa, India. The specific objectives of the evaluation were to: (i) learn whether the installation and use of the PLUM would be acceptable to householders with latrines, (ii) determine whether the device could be readily installed and recovered from latrines, (iii) assess whether the device was effective in sensing the presence of householders using the latrines, (iv) provide data that could be used to develop a methodology for interpreting and analyzing the PLUM output, and (v) compare the results from the PLUMs with results from structured observation to provide an initial validation of the PLUM.

■ METHODS

Design Parameters and Prototype Development. In rural, low-income settings in developing countries, sewerage is rare. Most sanitation is "on-site" and consists of latrines: hand-dug pits covered by or connected by a short pipe to a squatting slab or toilet.[16] The facilities are frequently surrounded by walls that are normally at least chest high, fabricated of brick, mud, wood, plants, woven grasses, cloth, plastic sheeting, or other available materials that provide some privacy. Some latrines are also fitted with doors or curtains over the entrance, as well as a roof. The wide variety of latrine types and construction materials is one of the challenges faced in designing a device that measures use.

We sought a solution that could discreetly detect and accurately record the use of most types of individual household latrines for at least a one week period. The latrine activity of

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interest was defecation, as elimination of open defecation is the main emphasis of sanitation programs in the study area. The device needed to be weather and tamper resistant, battery powered, easily installed/removed, acceptable to householders, and sufficiently low in cost for use in research and program assessment. We explored more than a dozen options. Devices that monitored the opening and closing of doors were ruled out because many latrines lack doors; others use plastic, cloth, or woven grass curtains that are not compatible with door monitoring systems. Active infrared detectors were considered but were believed to be susceptible to failure due to misalignment or obstructions. We ruled out video and automated still cameras, which are used to monitor hand washing and other behaviors,[17] because of concerns that they would be objectionable to householders and too costly for individual latrine applications. Pressure sensitive mats that would record people walking to or standing in latrines were considered susceptible to damage in these exposed environments. Embedding sensors in squatting slabs or in tubes that connect pans and pits may be possible in new construction but would require potentially complicated mechanisms that were not suitable for large-scale deployment.

We also considered using the ultrasound based "time-activity monitoring system" (TAMS) developed to monitor time that household members spend in close proximity to cooking stoves to assess exposure to indoor air pollution.[15] Because each member of the household wears his own unique transmitter, a receiver in the latrine would offer the advantage of providing data on the latrine use practices of individuals and not just the household as a whole. Individual monitoring may be particularly important to identify refractory householders who could then be targeted more directly in the intervention campaign. It might even be possible to use the TAMS to provide objective evidence of cases of diarrhea, which would be characterized by abnormally frequent latrine visits. While we continue to explore this approach, we ruled out relying on it here because of concerns about compliance (some individuals refuse or forget to wear the transmitters), limited battery life (48 h for the transmitters), and cost (about $400 (U.S.) for one household system of four transmitters and one receiver).

We ultimately decided to develop a new sensor platform using a passive infrared (PIR) motion detector called the passive latrine use monitor (PLUM; Figure 1). All objects with a temperature above absolute zero emit energy, including the infrared spectrum invisible to the human eye. A "passive" infrared device, as opposed to an active device, does not employ an infrared beam but simply accepts incoming infrared radiation. Apparent motion is detected when an infrared source with one temperature, such as a human, passes in front of an infrared source with another temperature in the background (walls, floor, etc.). The sensor we selected (#555-28027 PIR Sensor from Parallax, Inc.) is tuned to detect infrared radiation in the wavelength range emitted by human skin (and potentially other objects with the same temperature). Even if ambient air temperatures are similar to body temperature, there is typically enough variation in temperature over the surface of the body that a signal is generated. An onboard integrated circuit processes the information from the sensor into a simple binary output (absence or presence of motion of an IR source in the wavelength range of interest). Passive infrared sensors are widely used in industrialized countries as motion detectors for alarms and outdoor lighting.

Both the initial prototype (used for lab testing and proof of concept) and "second generation" PLUM (used for testing in the field) were constructed from off-the-shelf parts. In addition to the PIR sensor, an Arduino Pro Mini microcontroller for computation, a microSD shield for data storage, and 3 AA batteries for power were used. The complete assembly was contained within a 9 cm × 9 cm × 6 cm watertight ABS plastic housing with an aperture for the sensor window suitable for mounting on the ceiling or wall of a latrine where the sensor can view the area to be monitored (Figure 1). A thin polyethylene plastic sheet over the aperture makes the sensor invisible to householders and prevents the intrusion of dust or insects while still allowing IR radiation to pass through to the PIR sensor. The cost of the parts to construct this device was about $60.

Testing in the Field. After testing and development in the laboratory, we undertook a five-week evaluation of second-generation PLUM devices in Orissa, India. The fieldwork was approved by the Ethics Committee of the London School of Hygiene and Tropical Medicine and by the Institutional Ethics Committee of the Xavier Institute of Management, Bhubaneswar. We first conducted formative research in the target communities with focus groups and in-depth interviews of latrine owners to gain an understanding of local perceptions and practices with regards to sanitation, to identify any objections to the PLUMs, to ensure that they were functioning properly, and to solve any technical problems that may occur at this stage. The field work was conducted in five rural villages in Puri District in July−August 2010. Households were eligible to take part in the study if they had a fully functional latrine and consented to participate after receiving full details about the study. A random sample of about 25 eligible households was selected from the eligible households in each of five villages, and data were collected from each participating household for one week. PLUMs were installed for 8-day cycles at each household latrine. On 2 days of each cycle, trained enumerators were stationed to observe household members entering/exiting the latrines for 5 total hours (3 h during one early morning and 2 h during one early evening). The observer recorded the time household members entered and exited the latrine. This procedure resulted in 8 days of PLUM data and 2 periods of structured observation data for each participating household.

We compared dates and times of latrine entries for each household during the observation period. Data from structured observation were extracted from enumerator log sheets and recorded into spreadsheets. Data from PLUMs, consisting of a list of timestamps where movement occurred, were downloaded from the devices and imported into MATLAB (MathWorks) for analysis.

Interpretation of the PLUM Signal. The development of the PLUM interpretation algorithm was informed by a combination of controlled experiments during technical development of the device, field experiments prior to and concurrent with study deployment, and theoretical understanding of the PIR sensor characteristics. The steps of the process converting raw PLUM signals into latrine events are illustrated for one observation period in Figure 2. In developing the timing parameters for this process, a training set composed of data from seven households was used to guide selection; the reasoning behind the selection of each parameter is explained in the corresponding step.

The pane labeled "initial comparison" shows the raw output of the PLUM device and the structured observation data

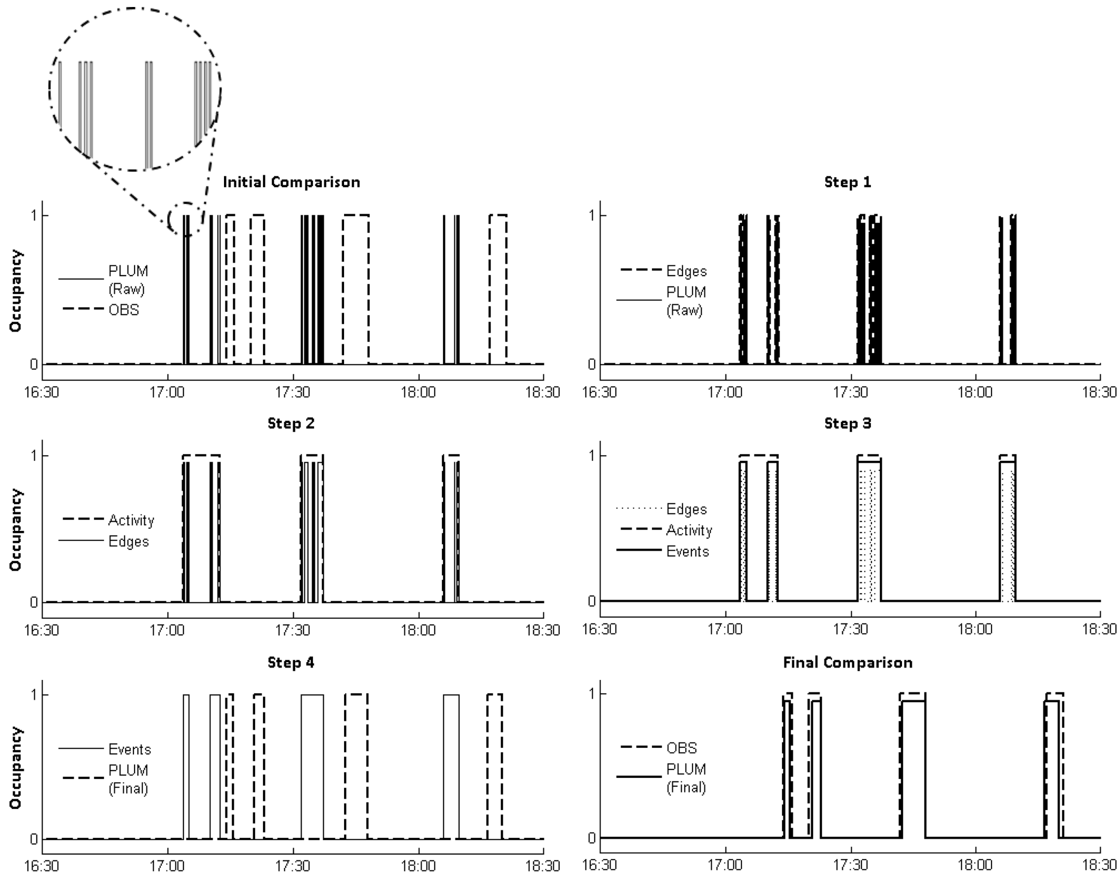

Figure 2. Steps showing process for developing PLUM data interpretation.

recorded for this observation period. In Step 1, raw motion triggers are lumped together into "edges" as long as they occur within 15 s of the previous trigger. Empirical tests revealed a common pattern of PLUM triggers associated with latrine usage: (1) dense triggering, presumably associated with entering the latrine, (2) sparse or no triggering, presumably when the user is relatively still while squatting, and (3) dense triggering, presumably during anal cleansing and exit of the latrine. Step 1 is intended to turn the periods of dense triggering into behavioral "edges" (entry/exit), hence, the nomenclature. Additionally, single triggers with no neighbors (no other triggers within 15 s before or after) are rejected entirely with the rationale that alone these triggers may represent spurious noise or nondefecation triggering behaviors (e.g., wandering people or animals) and should thus be ignored. If these ignored triggers ought to actually be associated with usage events, then the nearby edges will still be present and analyzed, not affecting the ultimate interpretation. The selection of 15 s for this parameter strikes a balance between associating successive triggering events that are part of the same movement while identifying the period of inactivity during squatting and was confirmed by sensitivity analysis.

In Step 2, edges are lumped into "activity" as long as they occur within 10 min of the beginning of the previous edge. This step is intended to combine all the edges associated with a single usage into one period of activity. This parameter is chosen to be overly inclusive; that is, setting this parameter to a value beyond the average latrine usage duration ensures that, during high-traffic usage, multiple latrine usage events will likely be lumped into a single activity. This lumping is done using the logic that while this step is sufficient for low-traffic periods when usage events are sparse, greater scrutiny can be applied to longer activity periods that may contain multiple events, aiming to determine whether and how to split the activity into multiple events. Increasing the length of this parameter beyond 10 min had little effect, as activities are eventually separated into a series of events. However, decreasing the length of this parameter may cause a longer latrine event to be incorrectly classified as multiple latrine events. Additionally, during this step, edges shorter than 30 s that have no neighbors (no other edges within 10 min before or after) are rejected, under the assumption that they more likely represent nondefecation behaviors such as entering the latrine only briefly to replenish water for anal cleansing or to dispose of child faeces. This parameter has been chosen to exclude events that are likely too short to be complete defecation events. As discussed later, however, the inability to distinguish between different behaviors is an acknowledged limitation of PLUM.

In Step 3, activities longer than 6 min are re-examined to determine if they comprise multiple events. If within these activities there are any periods with no edges for at least 3 min, the activity is split at these gaps. The intent is to separate high-traffic events that were lumped together in the overinclusive activity step. The selection of these parameter values follows from a sensitivity analysis performed on the training set, aiming to find a balance between separating events from longer activities without dividing events themselves. However, setting this parameter to 3 min has the effect of placing a theoretical limit on the performance of the PLUM in high-traffic situations, causing the devices to systematically undercount latrine usage events that occur within 3 min of each other.

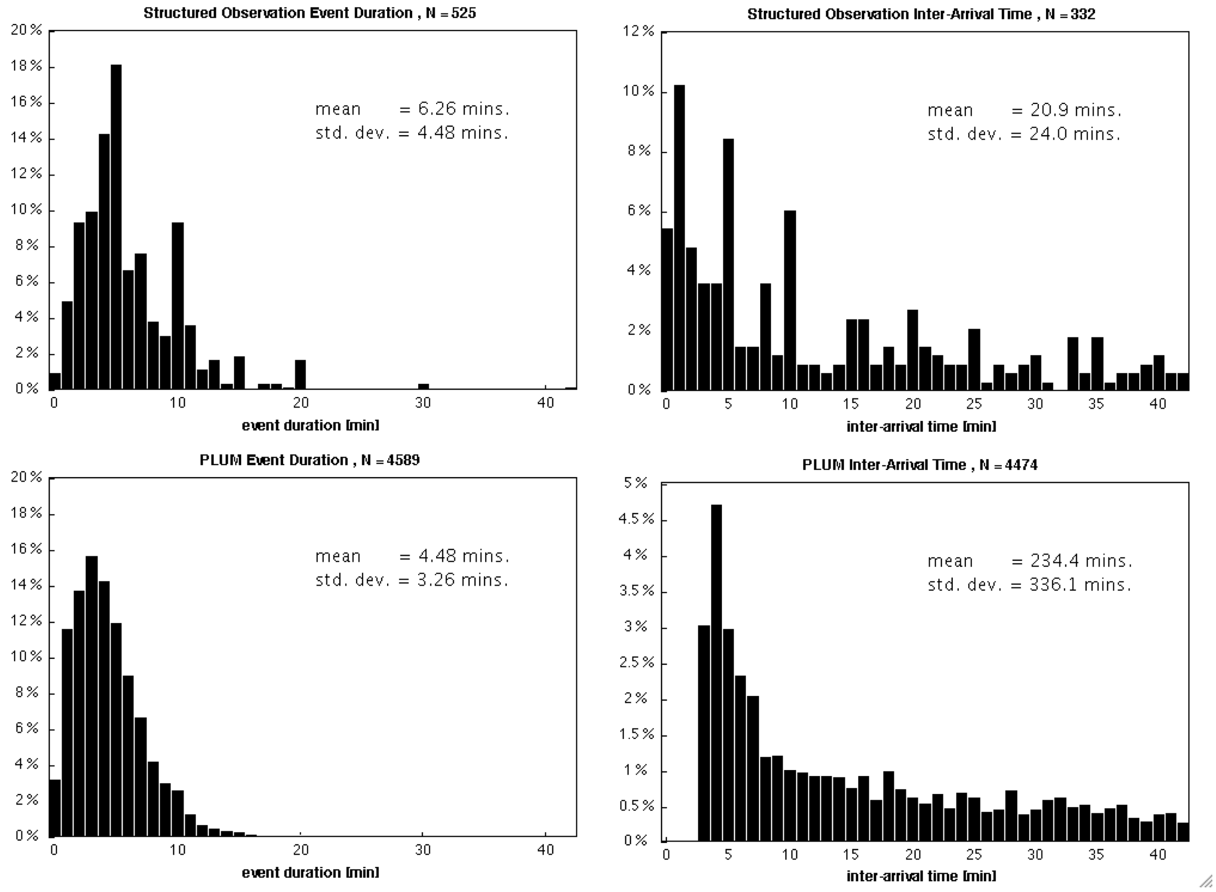

Figure 3. Comparison of PLUM results and structured observation, by event duration (left) and interarrival time (right).

The "events" that are defined after Step 3 are the best measure of latrine usage offered by the current generation of PLUM and interpretation software. However, for purposes of comparison with structured observation, one additional processing step was necessary. Because the study methods involved multiple parties recording times (the researcher logged the time that each PLUM device was initialized and the enumerators recorded the structured observation times by hand), there are temporal discrepancies between the two data sets. This discrepancy manifests in two ways: (1) as an absolute global offset due to the difference between the set time of the time pieces used by the different parties as well as systematic human error and (2) as small, local offsets due to the quantization noise introduced by rounding event observation times. For example, in the case of the observation period depicted in Figure 2, a temporal offset is visible between the PLUM data and the structured observation data. While the overall shift is small and not important for studying sanitation behavior, it results in PLUM events being inappropriately shifted in or out of the observation window. Consequently, for purposes of statistical comparison between the PLUM and structured observation, Step 4 shifts PLUM events by up to an hour in either direction to identify the shift that results in the highest degree of overlap with the corresponding structured observation. Because the deployment periods were short (8 days), any drifting of the individual time pieces (the PLUM clock, or the observers' watches) is considered to be negligible. However, long-term deployments of PLUM devices may experience clock skew due to imperfections in the timing crystal on the device. This "shifting" is the only step of the interpretation process that utilizes the structured observation data, and it is performed only to overcome the temporal discrepancies between methods for the purposes of this validation-oriented study.

RESULTS

Acceptability and Data Collection. There was little objection to the installation of the device in latrines; only one of the eligible households selected to participate in the evaluation declined, though two households removed the device during the trial period due to subsequent concerns. In most cases, plastic zipties were used to mount the devices, though when no suitable mounting position was available, mounting holes were drilled into the masonry. During the 5-week evaluation, we enrolled 132 participating households. PLUM data from eight households (6.0%) were not collected due to hardware failure (detached batteries, loose detectors, etc.); data from an additional nine households (6.8%) were deemed unreliable as a result of constant triggering of the detector, indicative of device failure.

Comparison of Data from Structured Observation and PLUM. The distributions of event duration (the time between entry and exit of the latrine) and interarrival time (IAT; the time between exit and successive entry) as recorded by structured observers are shown in the top two panes of Figure 3. The same information from the PLUM appears in the bottom two panes of Figure 3.

The first feature of the data that is apparent is coarse granularity. The enumerators performing the structured observation were instructed to record entry and exit of the latrine to the nearest minute, but times were frequently rounded to the nearest 5 min (e.g., 7:25 or 8:10 rather than 7:23 or 8:11). This feature is visible in the structured observation duration and IAT histograms in the form of pronounced protrusions above the underlying trend at 5 min, 10 min, 15 min, and so on.

The second feature of note is that the distributions of duration and IAT overlap significantly; many subsequent events arrive within a duration that could easily be misconstrued as continuations of the current event. Though structured observation should recognize the separation between events in this type of case, there are significant implications for the interpretation of the PLUM data. Perhaps the simplest scheme for converting the raw motion triggers to latrine entry and exit would be to lump all triggers that fall within an empirically determined time threshold of the previous trigger into a single latrine use event. The time of the first trigger in the bunch would then correspond to entry and the time of the last to exit. However, since the duration and IAT distributions overlap significantly, subsequent triggers are just as likely to be successive usage events as continuations of the current event. This overlap motivates development of a better informed and more discriminating interpretation algorithm and will be a focus of future work.

The duration and interarrival time according to the PLUM data are given in the bottom two panes of Figure 3. The PLUM data do not exhibit the coarse granularity that is pervasive in the structured observation data. The aforementioned event under-counting bias in high-traffic scenarios (introduced in Step 3 of the interpretation process above) is apparent when comparing the structured observation and PLUM IAT histograms, as by definition the minimum IAT measured by the PLUM is 3 min. Despite the fact that this systematic undercounting results in fewer, longer usage events, the duration of structured observation events has a mean of 6.26 min and a standard deviation of 4.48 min, while the duration of PLUM events has a mean of 4.48 min and a standard deviation of 3.26 min.

As a simple metric of comparison between the two methods, the number of events recorded in a given observation period is examined. A histogram of the difference in event count between the two methods, $n_{obs} - n_{PLUM}$, for the 228 observation periods is provided in Figure 4. The event counts agree exactly for 52.2% of observation periods, are within one event for 80.7%, and are within two events for 93.9%. Also apparent from the figure is the tendency for the PLUM to undercount latrine usage events.

Latrine Usage Event Count. Over the course of the field evaluation, structured observation captured only a proportion of the total latrine usage activity recorded by the PLUM by virtue of the limited observation periods. The left pane of Figure 5 shows the distribution of unprocessed motion triggers recorded by the PLUM by time of day. The typical observation periods used in this study are highlighted. The right pane of Figure 5 shows the proportion of equivalent PLUM data that is captured by structured observation if the observation periods are extended symmetrically about their center points, 6:30 and 17:30 (supposing that both observation periods occur on the same day, which was not typical). When the observation periods have not been extended beyond their center points, no PLUM data are covered. When each period has been extended to 12 h (6 h before and after the center point), all PLUM data are encompassed. The steep initial slope of the curve indicates that the times of day have been well selected, as approximately

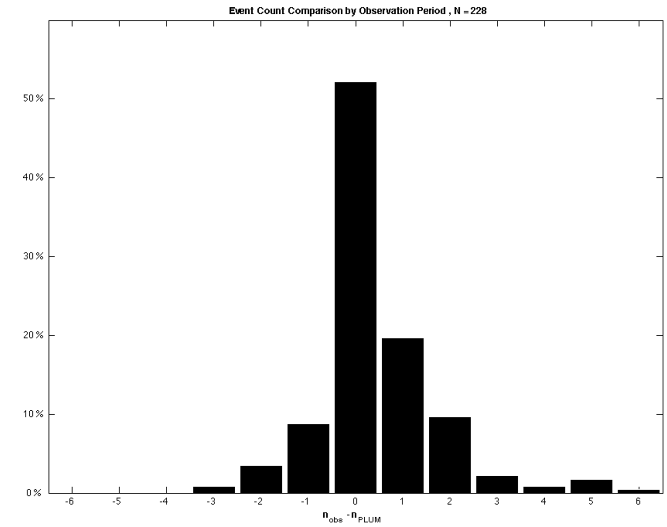

Figure 4. Comparison of PLUM results and structured observation results, by latrine usage event.

47% of daily latrine usage activity occurred within the 5-h observation periods. Unprocessed motion triggers were used for these analyses because the data set is large and spread throughout the trial, as opposed to the more sparsely collected structured observation events.

The preceding analysis applies for a period of one day. In practice, structured observation took place only on certain days (in this study, 5 h split into two periods on different days over the course of an 8 day trial). Excluding PLUM installation and retrieval days (for reactivity concerns), an average of 12% of the events covered by the PLUM was covered by structured observation.

PLUM results also provide strong evidence of reactivity (Hawthorne effect) on the part of the study population in response to structured observation of latrine usage behavior. A comparison of the number of events recorded by the PLUM during an observation period versus the number of events recorded by the PLUM during the same time period on days without observation is provided in Figure 6. More events were recorded by the PLUM when structured observation was taking place, both during morning (mean, 2.71 versus 2.11, $p < 0.002$) and afternoon (1.03 versus 0.53, $p < 0.001$) observation periods.

DISCUSSION

Algorithm Design Process. Design of the interpretation algorithm of raw PLUM signals was highly iterative, with improvements guided by a combination of our observation of the training data as well as our understanding of typical latrine usage behavior in this setting. Our initial formulation of the interpretation algorithm attempted to simply bundle adjacent raw PLUM signals within a certain period into latrine usage events. However, we discovered that this process tended to be either too aggressive in lumping signals together if the period was too large or too fine-grained to account for the typical pattern of a latrine usage event as seen by PLUM, whereby significant motion activity at entrance precedes a brief lull during the defecation event and more significant motion during the cleansing and exit process. Thus, a two-stage process was developed, with initially aggressive inclusion into "activities" followed by a higher-resolution analysis to determine individual

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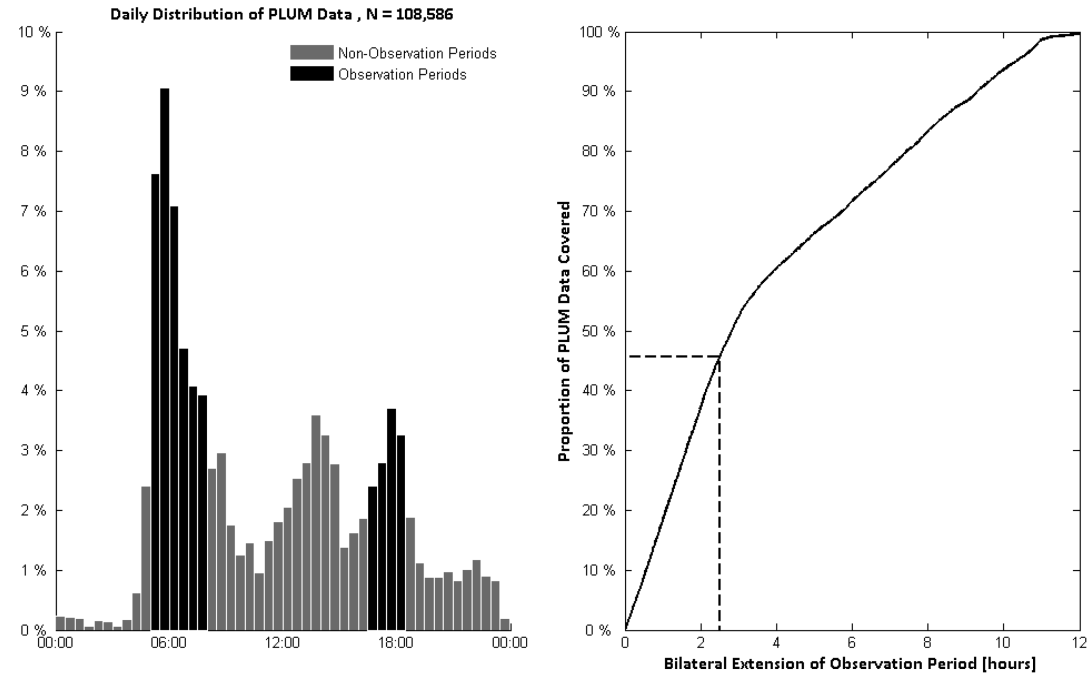

Figure 5. Comparison of coverage of latrine events by the PLUM and structured observation.

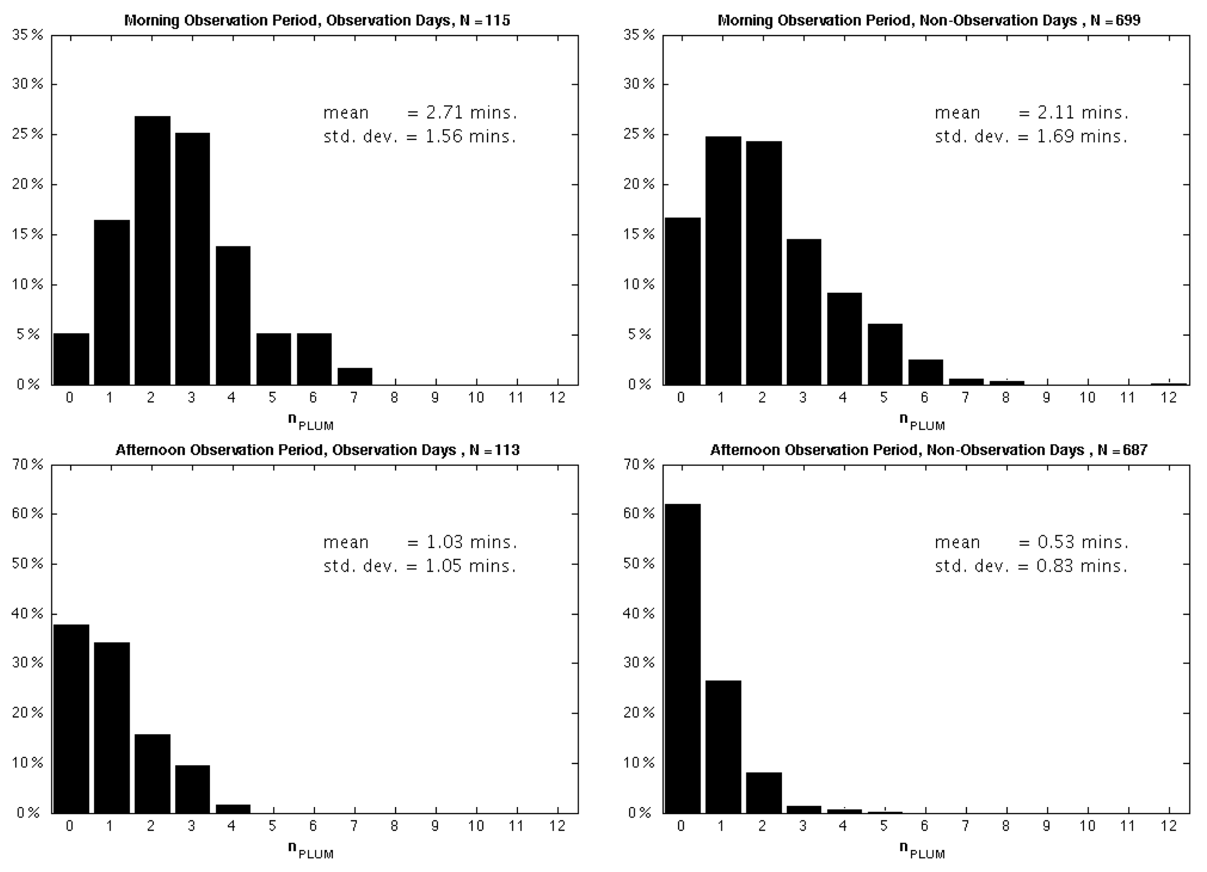

Figure 6. Comparison of latrine events as recorded by the PLUM during morning (above) and afternoon (below) periods of structured observation (left) and nonobservation (right).

latrine usage events. The parameters governing this process were chosen by employing a combination of physical understanding of the process and sensitivity analysis. We recognize that the analysis steps and parameters may be particular to interpreting the PLUM signals from the specific study site, given the unique features of the latrine structures, defecation and cleansing behavior, and device orientation. Deployment of PLUMs in different regions will allow us to determine whether the interpretation algorithm needs further refinement to accurately reflect latrine usage in a variety of communities. In future work, we will examine whether it is possible to arrive at a similar heuristic computationally, rather than using an intuition and observation-driven process.

PLUM Hardware. The second generation PLUM device met our key design parameters. In the field, the PLUM proved to be acceptable to householders and relatively easy to install/remove by researchers. Although air temperatures were sometimes similar to body temperature, there was no evidence that the PIR signal decreased (data not shown). The 6% hardware failure rate is high but, like cost, should improve when fabricated from custom-designed components. Our chief problem with the device was the need to remove the housing cover (secured by four screws) to turn the device on and off and to remove the SD card for downloading the data. The short battery life and lack of an indicator of remaining battery life also required that we replace the batteries after each installation.

Comparison of PLUM and Structured Observation. The field evaluation results identified some shortcomings with structured observation, which is the current gold standard for measuring latrine use. We found evidence of rounding in records from observations, suggesting some lack of precision. Data from structured observations yielded a higher mean and variance of events compared to the PLUM, providing evidence of quantifiable errors. We also found strong evidence of reactivity (Hawthorne effect) from conducting structured observations: householders were more likely to use their latrines during periods under observation. While such reactivity has been documented in structured observations of hand washing and other promoted behaviors,[18] this is the first evidence of the effect in connection with latrine use. Once installed, the PLUM continues to record activity around the clock and for extended periods of time, offering an uninterrupted an extended perspective on the behavior that may be difficult or costly to characterize with direct observation. Readily analyzable data can be downloaded quickly and accurately, minimizing the time and potential errors from entering data from paper records. The PLUM data also shed light on how structured observation could be used most effectively, by illustrating the diurnal pattern of latrine use, such that a high proportion of daily latrine events can be captured by deploying observers at key times.

Some important limitations of the PLUM device were identified. One limitation was the inability to disambiguate latrine events that occurred with short interarrival times. A minimum event separation period of 3 min was chosen somewhat arbitrarily for our analysis, and future efforts could be directed at refining the algorithm to more accurately interrogate and interpret the signal during consecutive use periods. Alternate installation locations or multiple sensor platforms may be needed to more accurately count events during high-traffic periods (e.g., early morning) or high-traffic situations (e.g., shared latrines). A related limitation is that the current sensor does not provide information about what the latrine activity is (e.g., entering vs exiting), but only that activity is occurring. Moreover, the device cannot inherently distinguish defecation from other behaviors, such as urination, disposal of child feces, menstrual hygiene, and latrine cleaning, which are important factors in designing and evaluating sanitation solutions that meet the many needs of target households. The PLUM also lacks the capacity to identify which members of the household are using the latrine. While it may be possible to develop a user profile that distinguishes patterns suggesting that some householders are not using latrines, the device cannot currently identify those refractory members so that they can be investigated further or targeted for outreach. Thus, more sophisticated questions about latrine behaviors will be better addressed by combining PLUM measurements with ethnography and other qualitative research methods and by development of more complex sensor platforms. Nonetheless, the low-cost, simple PLUM design evaluated here has many advantages over current methods and has the potential to enhance measurement of latrine use so that many questions that are critical to developing effective sanitation programs can be more effectively addressed.

Implications for Sanitation Research. Among the MDG development challenges, few are as intractable as sanitation. While governments, NGOs, and others are undertaking sanitation campaigns, there is risk that success will be measured simply by changes in latrine coverage without addressing whether the latrines are actually used, which is a necessary condition to achieve the intended health, livelihood, and environmental benefits of improved sanitation. While not intended to replace other measurement methods, the PLUM offers an improved tool for researchers, project implementers, and program evaluators to assess and improve latrine use.

The field evaluation has provided valuable feedback that will be used to improve the PLUM for future deployments. For example, priorities include designing a custom circuit board, standardizing the sealing and mounting process, integrating a wireless interface for data collection, increasing the battery life, and developing a standardized data format to streamline the data cleaning and analysis process. In light of these improvements, a third generation PLUM device is currently being deployed at larger scale in sanitation research in India, with additional deployments in Kenya and other countries expected in 2012. This and other experience will improve our understanding of the role that the PLUM technology offers in making sanitation count.

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Notes

The authors declare no competing financial interest.

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