Instrumentation for Cooking Pattern Analysis in Peri-Urban Nepal

Shengrong Yin*, Amod Kumar Pokhrel†, Milad Heydariaan*, Omprakash Gnawali*,
Lal Bdr. Reshmi Thapa‡, Santosh Regmi‡, Dhiraj Pokhrel§
*University of Houston, †UC Berkeley, ‡Kiev Technologies, §Leaders Nepal

***Abstract*—Clean Cooking is essential to maintain a healthy lifestyle. However, many people in developing economies do not have access to clean cooking. To promote clean cooking, first, we need to understand the cooking patterns in the household, and second, design interventions over those patterns. We also need to understand the grid and power supply readiness to support electricity-based clean cooking initiatives. In this paper, we provide an affordable and scalable energy monitoring system solution to instrument the cooking pattern in peri-urban Nepal. Our design consists of off-the-shelf power meters, minor changes in sockets/wiring at homes, data upload using cellular radio, and standard dashboard and analysis in the cloud. We deployed the system in 35 households in peri-urban Nepal and collected data from early August until the middle of October 2019. Our preliminary study indicates: 1) Cellular data access is a viable way to upload instrumentation data to the Internet in studies of this nature. 2) Data integrity and reliability are closely coupled with user behaviors and cellular reliability. 3) Deployment can be centralized instead of distributed, and cost can be affordable. 4) Continuous data collection from about three months shows poor power quality in the area.**

***Index Terms*—Energy Monitoring, Clean Cooking, Internet of Things, Electric Cooking, Nepal, Cloud Technologies**

I. Introduction

A large fraction of the rural population in developing economies still cook with solid fuels (woods and coal) to save on electricity bill [1] or due to unreliable or inadequate supply of electricity in rural areas. Cooking with solid fuels is harmful to people's health as well as the environment. National governments and international development agencies are promoting electricity-based cooking devices to replace solid fuel stoves in developing countries [10].

Policy-makers and the government entities need to understand the energy usage from electric stoves and cooking patterns to plan the electricity grid upgrades to support higher load and create incentive programs for the poor to use clean energy. Such data-driven policy-making and implementation are likely to optimize and prioritize resources in the right places and increase the chance of success for eventual large-scale adoption of these technologies. Thus, an instrumentation system is required to collect the energy data from the households to design clean cooking interventions.

Household-level instrumentation of cooking stoves in rural and low-resource settings can be challenging due to economic, technical, and logistical reasons. The IoT-based energy metering solutions from the leading western vendors are too expensive for researchers in these settings, especially because many of the metering vendors bundle cloud and 3G solutions at a high price, often reaching hundreds of dollars per device. The metering solution should be affordable, customizable, and safe. It is possible to build a device that has the desirable properties from scratch, but that will make this instrumentation inaccessible to many researchers because they may not have embedded systems researchers or engineers in their teams. Even if one were to build such a device comprising of electric sensing, communication, and computation components, it would not be easy for it to obtain safety certification to make it safe for deployments at people's homes in proximity to the cooking areas. The second challenge is how to deploy on a large scale, and the location of the deployment may span hundreds of miles. As a result, maintenance on the device locally will be extremely difficult if remote access is not enabled or if the system is not built on common platforms. The third challenge is to ensure data integrity. As the data is transmitted over the cellular radio, the cellular signal in developing economies can be unreliable, and packets can be dropped or corrupted on the air.

To address this challenge, we design and implement an affordable, efficient, and reliable IoT system that can deploy easily and require little maintenance in a large geographical area in the developing economies. The system consists of an off-the-shelf inexpensive power meter, an off-the-shelf cellular radio system utilizing local cell operators for data upload, and industry-standard software in the backend to archive, analyze, and visualize the data. The system can stream the data from households to the backend in real-time. Policy-makers and local governments can leverage the system for decision-making such that health benefits with clean cooking can be pushed to the next level.

Our contributions in this work are:

- Describe an electricity use instrumentation system that is appropriate for challenging low-resource rural environments. The design emphasizes off-the-shelf components so that similar systems can be built and utilized by other researchers.
- Preliminary insights and lessons learned from the deployment of such instrumentation in 35 homes for nearly three months in rural Nepal. Our findings suggest that this approach for instrumentation is not perfect but feasible.

II. Related Work

There are a large number of energy-monitoring, including sub-metering solutions available in the market. Some of them are expensive for our scaling requirements, use specific hardware/software technologies that would be difficult to service by local technicians, or are not built robustly enough to be used in challenging environments in rural homes in a developing country.

FarmBeats [11] introduced a scalable IoT network that helps farmers to monitor the temperature and humidity of the growing crops. The architecture focuses on large-scale and multi-dimensional data collection. A commercial IoT VM instance is used in the project for data storage and analysis. The system provides an example of successful field sensor data collection over cellular networks. We also considered LoRaWAN technology but opted against it to minimize the introduction of hardware and software that the local support staff are not familiar with. Smart metering with cellular networks [7] discusses the benefit of using cellular networks to collect the metering data. Although we also use cellular data upload, their solution is also not feasible for energy monitoring of a single appliance.

Sense [6] is an energy-monitoring device that is capable of sampling the current at a sampling rate of up to 1 MHz. However, the sense product price tag of $299 is beyond our budget because we plan to scale to hundreds of households.

In this work, we design and implement a cost-effective smart metering system for electric stoves that spans device deployment, data communication, data management, and data visualization. We present initial insight and deployment experience from this work.

III. Objectives

In this project, we aim identify the economical aspect of electric stoves in rural Nepal. To provide meaningful data to both policy-makers and the residents living in peri-urban and rural areas, we need a cost-effective and easy-to-use IoT system to monitor energy from the electric stoves. The system design needs to meet the following objectives.

- **Low-cost:** We need to assemble and deploy customized power meter in the rural area for the developing economies. The devices and sensors are required to be low-cost and highly efficient.
- **Reliable:** Once the device is powered on, it should periodically sense energy data and upload it to the cloud for processing. The data update frequency is configurable with the finest granularity in seconds.
- **Easy-to-manage:** The deployment covers a large geographical area. Once the device is deployed, it becomes difficult to be maintained locally; hence, it should require minimum maintenance and should leverage local technician skills.
- **Always-connected:** We need to connect all the deployed IoT devices online to monitor cooking events that may happen at any time. The only feasible way to do it in the rural area is to use the Cellular network. The data needs to be uploaded to the cloud for storage and analysis. The data delivery system should be able to handle intermittent and unreliable cellular connections.
- **Semi Real-time Analysis:** It is desirable to provide a dashboard with real-time data insights also to the users. Users may be able to predict their energy use cost trends and make decisions on electric cooking based on economics.

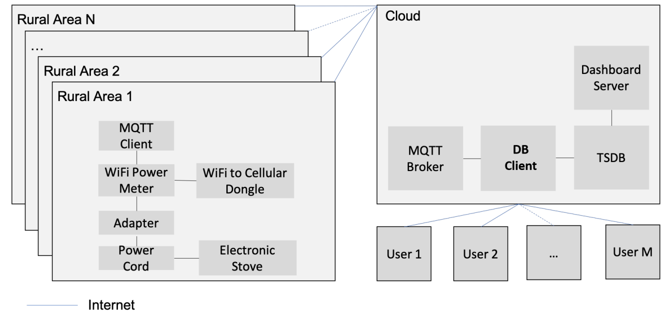

Fig. 1: Design of the electricity sensing system

IV. System Design

We present a sensor system design architecture (Fig. 1) that meets the objectives outlined in Section III.

The following components are used in the deployment.

- **Electric Stove:** People in developing economies barely use electricity for cooking activities [2]. The use of electric stoves can help accelerate universal access to clean cooking. Typically, when the electric stove is powered on, the current spikes. The use of electric stove during peak time can draw substantial amount of power from the grid, causing the voltage to drop in the households. All these changes should be captured and saved for the demand analysis.
- **Power Socket Adapter:** We identify the power socket plug type that can match the power cord of the electric stove. The plug adapter is bundled with the wireless power meter and the USB dongle that serves as a WiFi-to-Cellular adapter.
- **WiFi Power Meter:** We utilize off-the-shelf smart plug that can meet the requirements of safety certification instead of designing a customized power meter. We use the commercial smart plug, Sonoff S31 [8] as the wireless power meter. Sonoff S31 is a WiFi plug with energy monitoring. It can be plugged into a power socket and can monitor voltage, current, power, and power factors. The accepted input voltage can range from 90 V to 250 V. The maximum detectable current is 15 A. The energy consumption for the electric stove is within this range. The teardown of Sonoff S31 [9] indicates that the device has an energy monitoring block, a transformer block to power on the energy monitoring block, and a wireless communication block, and it allows the end-user to flash customized firmware. The key components

in the S31 device are the ESP8266 chipset and the energy monitoring sensor, CSE7766. We build on the open-source Tasmota firmware. Table I shows the cost per deployment package.

- **USB WiFi-to-Cellular Dongle:** The Internet infrastructure in developing economies is primarily the cellular network. Thus, a cellular-to-WiFi gadget is required to forward the data from the WiFi power meter to the cloud. It can be powered with a USB port so that deployment can be plug and play. However, it still requires configuration to set the dongle into WiFi AP mode, and the access credential needs to be programmed into the WiFi power meter such that the WiFi connection between the dongle and the power meter can be provisioned before the deployment.

On the cloud side, the software stack is integrated with the following components on a virtual machine, launched from one of the leading cloud service providers. In this way, the availability and reliability of the backend can be assured.

- **MQTT Broker:** The design uses MQTT [5] as the connectivity protocol between the edge device and the cloud. The MQTT client can be written to the power meter firmware for its lightweight transport and small code footprint. Before the deployment, we need to configure the backend with a fixed IP to configure the device to connect to the MQTT broker once it is powered on.
- **DB Client:** On the backend, we implemented a script that subscribes to an MQTT topic to extract the energy data and then ingests the message into a time-series database.
- **TSDB:** The design uses influxDB [4], an open-source time-series database with a fast-growing number of enterprise users, as the time-series database.
- **Dashboard Server:** The design uses Grafana [3], an open-source full-stack visualization solution that supports queries to multiple databases and provides an easy-to-use and customized dashboard for the end-user.

V. Deployment

In the first stage of this project, we deployed 30 devices in the field over two municipalities in central Nepal.

Fig. 2 shows the sensor deployment in the kitchen of a household. We used a local 3-pin power plug to convert the socket to be compatible with the US-style Sonoff socket. The 3-pin adapter also provides a USB port to power the ZTE MF70 3G Router, which serves as a WiFi access point. Once Sonoff is powered on, it searches for the SSID of the WiFi access point and starts to connect to the cellular dongle. The process is seamless, and no configuration is needed in the field. The three components are integrated and configured in the lab such during the deployment, once it is plugged into the power cord, it starts to stream the data.

Installation Complexity: Installation complexity is a major challenge to deploy energy monitoring systems in buildings even in developed countries. Although we had designed the system to be easy to install, we still spent 1-2 hours at each household for installation as we need to wire the smart plug

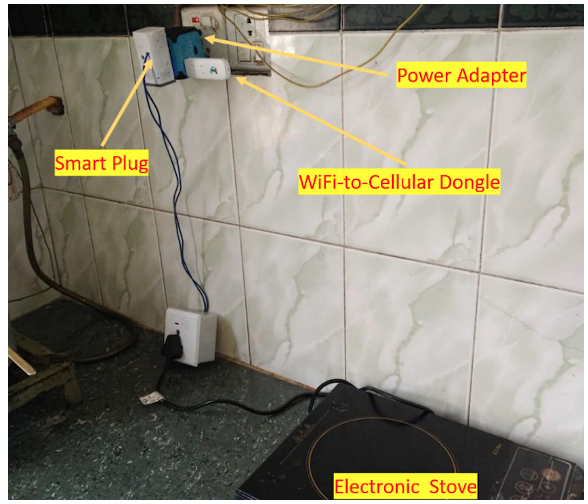

Fig. 2: Electricity sensor deployment in a rural household

TABLE I: Part lists Per Deployment

Item	Model	Parts	Cost
Smart Plug	Sonoff S31	ESP8266 CSE7766	$17.00
WiFi-Cellular Adapter	ZTE MF70 Router 3G 850/1900 Mhz	USB Dongle SIM card	$25.90
SIM Card	1500 MB data pack	Monthly	$3.35

to make it compatible with the power socket in the household. Sometimes, we had to do some rewiring in the kitchen. We also needed to train the households on how to turn the metering off if they choose to and to monitor its status. We also needed to do a basic in-field calibration with the electric stove the households had. To simplify the installation, a new form factor for the smart plug needs to be redesigned to fit the existing power socket in order to scale to hundreds of installations.

VI. Preliminary Result

In this section, we present preliminary results from the initial deployment. We select device T005 for a sample overview of the data quality. Fig. 3 shows the voltage and current recorded for nearly three months. The two circled areas show no data points recorded. The data loss is likely due to power outage in the area. There are also several data (spike downs) points showing 0 V in the plot, likely due to a sensor glitch. The plot for current shows a lot of spikes, and each spike can be one cooking event using the electric stove. The voltage samples recorded on T005 show a max of 276 V, a minimum of 0 V, an average of 215 V. The standard deviation of the supply voltage is 10 V over the 2.5-month data record. The current samples on T005 show a max of 6.43 A, a minimum of 0 A, an average of 0.1 A over the same period. Table II describes the data outage frequency during the same period. Although the devices were configured to collect and send sensor reading every 10 seconds, the cloud server received data with a large inter-sample variation. There are 2375 times where the average sample interval from the top 5 devices is larger than 1 minute, likely due to unreliable cellular connectivity;

Fig. 3: Voltage and Current recorded by T005 from Aug-01-2019 to Oct-15-2019.

TABLE II: Data Outage Frequency from the top five devices with samples collected from Aug-01-2019 to Oct-15-2019

Top 5 Devices	**Over** a minute	**Over** an hour	**Over** a day	**Over** a week
Avg. Samples	2375	15.6	1.6	0

15.6 times where the sample interval is larger than 1 hour, likely due to power outage, 1.6 times where the sample is larger than 1 day.

Aggregate data from all the households show the average power drawn by the electric stoves was 811 W. The voltage at times drifted down to 180 V despite the 230 V nominal voltage, and patterns of lower voltage are more common at households farther from the distribution transformers. These low voltages and power outages could discourage electric cooking. The cooking peaks were during 6 to 8 a.m., 2:30 to 3:30 p.m., and 5:30 to 7:30 p.m. The households used in average, 20 kWh of electricity for cooking.

VII. Discussion

a) Feasibility of Cellular network for instrumentation: We found that using Cellular network for instrumentation is feasible.

b) Decoupling meter from the device: We found that the residents sometimes unplugged the power meter (despite being instructed not to do so) because they thought the power meter may be consuming power and costing them money.

c) Sensor Calibration: We found that in-field coarse calibration can complement in-lab fine-grained calibration.

d) Data outages and their implication on data analysis: Data outages typically correlates to network or power outages. Data outages are a serious challenge to data analysis. Another data issue we faced is irregular sampling due to sporadic data losses, which can cause simple cooking event estimation not workable, and we had to design sophisticated heuristics to estimate these intervals.

e) Opportunities for secondary analysis: The data outage that is correlated in a vicinity could be due to power outages so we may be able to estimate when power outages occur by finding correlated data outages.

f) Platform improvements: We will improve the firmware on the platform to provide additional instrumentation to help improve the device diagnostics and obtain additional data on electric stove use patterns.

VIII. Conclusions

In this paper, we designed and implemented an energy monitoring system that can help the instrumentation of cooking pattern analysis in peri-urban Nepal. Initial deployment indicates a cost-effective solution that is ready for wider deployment. We hope this design and experiences with the platform can be useful to other researchers.

Acknowledgment

This work was supported in part by the United Nations Foundation (Grant # UNF-18-997 and PR-19-42221).

References

[1] Clean cooking alliance. https://www.cleancookingalliance.org/about/news/04-26-2017-maximizing-the-health-benefits-of-clean-household-energy-in-urban-nepal.html.

[2] Clean cooking: Why it matters. https://www.worldbank.org/en/news/feature/2019/11/04/why-clean-cooking-matters.

[3] Grafana: the open observability platform. https://grafana.com/.

[4] InfluxDB an open source time series platform. https://github.com/influxdata/influxdb.

[5] Mqtt. http://mqtt.org/.

[6] Sense. https://sense.com/.

[7] Smart metering with cellular networks. https://www.digikey.com/en/articles/techzone/2017/nov/cellular-connectivity-for-smart-metering.

[8] Sonoff s31 smart plug. https://www.itead.cc/sonoff-s31.html.

[9] Tinkerman sonoff 31 teardown. https://tinkerman.cat/post/sonoff-s31-now-serious/.

[10] S. Pattanayak, M. Jeuland, J. Lewis, F. Usmani, N. Brooks, V. Bhojvaid, A. Kar, L. Lipinski, L. Morrison, O. Patange, et al. Experimental evidence on promotion of electric and improved biomass cookstoves. *Proceedings of the National Academy of Sciences*, 116(27):13282–13287, 2019.

[11] D. Vasisht, Z. Kapetanovic, J. Won, X. Jin, R. Chandra, S. Sinha, A. Kapoor, M. Sudarshan, and S. Stratman. Farmbeats: An iot platform for data-driven agriculture. In *NSDI 17*.