Human-enabled Microscopic Environmental Mobile Sensing and Feedback

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1. Introduction

Climate change has had a dramatic impact on many agrarian developing nations. For example, in 2009, the delay of the monsoon rains by a month in India affected several macroeconomic factors including food price increases, a stock market slump, agricultural product export restrictions, and an array of agricultural subsidies. Over the past decade, there has been a growing trend in the number of farmer suicide deaths throughout the country due to a combination of economic, social, and environmental factors. On one hand, the fraction of arable land has decreased over the years due to soil erosion factors, excessive use of pesticides, and land encroachment from urban dwellers (buying land in rural areas). On the other hand, agriculture as an occupation has become less profitable due to a combination of poor yield (due to poor water availability, monsoon unpredictability, and soil erosion) and an increase in the cost of living. Many of these factors hint at a pending agrarian catastrophe.

From a technology perspective, what can we do to help agrarian communities in India and elsewhere? While we are not experts in economic and social factors, we do believe that technology can aid in addressing some of the environmental problems faced by such agrarian societies, even if it is in some limited manner that complements other efforts.

Our Vision

Our vision is to equip each individual with a inexpensive, comprehensive mobile sensing platform with a wide variety of environmental sensors that can enable any human to sense a range of environmental factors on a microscopic granularity and transmit this sensor data to a central environmental sensing system over the cellular network. Given the widespread proliferation of mobile devices in rural regions around the world, one can imagine this sensing platform either as an add-on device or an inbuilt sensing system with next-generation, low-end phones. Enabling any human to act as an environmental sensor is a powerful model since it enables the environmental monitoring system to gather information at a microscopic granularity, something that has been rare historically. Even if a few individuals within a region act as human-enabled mobile sensors, the granularity of environmental monitoring and prediction can be orders of magnitude more detailed than existing climate monitoring systems using fixed weather stations.

One obvious question is: why would farmers in villages be willing to act as human-enabled mobile environmental sensors? The answer to this question depends on how such an environmental monitoring system can impact the life of an average farmer: what useful feedback can such a system provide that is of significant utility for the farmer? Examples of feedback that might be of value to a farmer include:

1. *When to sow the seeds?:* With microscopic-level climate related information from a locality, can a monitoring system more accurately predict the arrival of the monsoon? Can the system provide feedback to the farmers to correspondingly alter their agricultural production cycle as a function of climate variations? Similarly, excessive rain is known to destroy large volumes of agricultural produce. Can such a system forewarn farmers in advance of excessive rain?
2. *Soil quality and erosion:* Using soil quality and moisture sensing from agricultural lands within a region, can the system accurately predict soil degradation and erosion in advance and provide information on alternative farming practices to enrich the soil? Can soil sensors be used to accurately measure the excessive use of pesticides and forewarn farmers of the erosion problem?
3. *Water availability:* Water availability is highly variable across different regions in India. Regions with local industry are known to consume large volumes of ground water, thereby significantly affecting water availability and land arability. Can we design sensors that can measure water availability both at a ground-water level and at a soil moisture level and provide appropriate feedback to the farmer?
4. *Crop portfolio:* Depending on climatic variations, soil quality conditions, and water availability, can the system also provide feedback on what crops are best suited for the given environmental conditions?

While these examples represent microscopic feedback at the level of the individual farmer, and they are important for encouraging farmers to participate in the system, there are many advantages that such a system can provide at a macroscopic level for climate modeling and prediction. For example, in an urban setting, mobile sensing systems can aid in pollution monitoring and detecting pollution "hotspots."

To enable both microscopic and macroscopic sensing, modeling, and feedback, we envision the mobile system supporting a wide range of inexpensive sensors including temperature, humidity, soil quality, soil moisture, air quality (specially for greenhouse and poisonous gases), chemicals, water quality, and ground water level. In addition, each device would use GPS to space-time stamp the readings.

The notion of using humans as mobile sensing vehicles has been explored previously and is the basis of many ongoing urban sensing efforts. N-Smarts (Honicky *et al.* 2008) and several other Mobiscopes (Abdelzaher *et al.* 2007) have roots in the citizen science movement (Irwin 1995). Some of these projects focus on air quality measurements but our approach differs from these prior mobile sensing efforts in both focus and application. Our goal is to use human-based mobile sensing in developing regions to study macroscopic (e.g. climate change, climate variations, ground water availability, and pollution) and microscopic properties (e.g. soil quality, soil variations, and groundwater levels), as well as provide appropriate and useful feedback to participants in order to encourage continued, sustainable participation.

2. First Steps in this Direction

Recent efforts provide some promising results in both sensor platforms and inexpensive data collection from mobile devices. Once data are collected, however, the real challenge of analyzing, modeling, and making predictions begins.

Microclimate Sensing with Cell Phones. Our recent work has demonstrated the feasibility of integrating a cell phone core radio, GPS receiver, Bluetooth, and wireless sensor interface with light, temperature, humidity, orientation, carbon monoxide, ozone, and nitrous oxide sensors in a handheld package (Dutta *et al.* 2009). Going forward, we believe that such devices can be integrated into mobile phones and also serve as "data mules" for embedded soil or fixed weather sensors. But using them as sensor endpoints raises many new issues. How can the unknown biases introduced by people be masked? Does sheer scale obviate fine-grained calibration? How can privacy be preserved?

Reducing Operational Costs. The price of connectivity in rural areas for voice, data, and messaging services are relatively expensive compared with local purchasing power. When data connectivity is not available in rural areas, SMS becomes the primary means of data transport. However, SMS is the least economically viable option using a *cost per bit* metric. Unfortunately, most existing mobile applications and services are not designed to optimize operational communication costs. An unoptimized application can dramatically increase the communication costs. To partially address this concern, we have built Efficient Lightweight Mobile Records (ELMR) (Kumar *et al.* 2009), a system for supporting SMS-based applications on top of an SMS-based protocol stack optimized for minimizing operational costs of the application. ELMR supports a semantic compression engine which can significantly reduce the number of bits used on the SMS channel by applications by developing an app-specific, semantic codebook for representing information. We envision using the ELMR system as a base platform for building our mobile sensing applications.

3. AI Research Challenges

Today, agricultural forecasting in developing regions is largely built on a top-down model – macroscale climate measurements are used to predict mesoscale weather effects – with the attendant lack of granularity and fidelity. In contrast to this approach, we envision crowd-sourcing microclimate, water and soil quality data collection. By leveraging ubiquitous mobile phones with inexpensive sensors and local soil measurements, we believe this relationship can be inverted – predicting mesoscale climate effects on agriculture using a network of microscale sensors – employing an iterative development and deployment model, and with attendant improvements in sensing granularity and fidelity.

Several AI research challenges emerge in this effort. First, devices may be poorly calibrated and may exhibit high variability in the measurements due to individual bias, aging, and other factors. In this context, which techniques should be used to cull the signal of interest from bias, noise, and interference? Second, can we better predict mesoscale climate, water, and soil patterns from poorly calibrated microscale measurements than we can from macroscale climate measurements? A related challenge is to build online models for weather predictions that combine traditional macroscale climate measurements with a large volume of micro and mesoscale human-enabled measurements. Finally, such a system will be successful only if it can provide actionable information to end-users to motivate large-scale user participation; determining the nature of feedback and how to predict it as a function of the data utility are fundamentally challenging AI problems.

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