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Abstract: We describe the ongoing design of a sensor network for small family farms in rural Kenya. The sensor network is just one part of an 'ecology of resources' in which handheld devices are used to bridge the sensor network and a computer-based access point. We describe the two villages where the system is deployed and the user requirements collected. We then describe the architecture of the sensor network and detail how it fits in with the larger integrated system. We then detail our approach to interface and interaction design, and conclude by describing the next steps in the project.

Keywords: interaction design; sensor networks; agriculture; mobile.

1. INTRODUCTION

In rural parts of developing countries, many people rely upon farming to provide food, yet lack valuable agricultural information about soil conditions, the weather forecast, pest and plant diseases, efficient irrigation methods, and crops they intend to grow. They also often lack basic literacy skills, and have little or no knowledge about Information and Communications Technologies (ICT). Agricultural information systems are common among large commercial farms in the developed world, but small, local implementations for the developing world require sensitive and participatory design practices, since existing technologies, interaction design methodologies, and usability testing techniques are all developed by and for the developed world.

One technology is nearly pervasive however: the mobile phone. For example in Kenya, the number of mobile phone users has gone from 300,000 in 2000 to more than 9 million in 2007; this is due in part to the fact that at any given time, two-thirds of the country's land lines are not working [Economist, 2007]. Mobile technologies can provide a two-way flow of information as rural farmers can not only receive data about markets, methods and pests, but also collect data on their crops which can be shared with scientists or shared databases.

Wireless sensor networks have also been proposed to help meet the information needs of the rural poor. For example according to Panchard et al [2006], information on the temporal and spatial variability of environmental parameters and their impact on farmers' crops, soil, and other aspects of farming can play a major role in formulating the farmers' strategy.

2. THE VESEL PROJECT

VeSeL (Village e-Science for Life) is a research project, part of the Bridging the Global Digital Divide network sponsored by the Engineering and Physical Sciences Research Council (EPSRC) in the UK. It runs for three years from September 2006. The aim of the project is to enable rural communities in Sub-Saharan Africa to use advanced digital technology to improve their agricultural practices and literacy levels, with particular emphasis upon educational barriers. This is a demand-driven participatory iterative which involves end users (farming communities) from the start, and develops and refines technological solutions based on their needs and with their ongoing participation in the design process.

In contrast to previous initiatives in this area, we view sensor networks as just one element in an ‘ecology of resources’ decision support system for resource-poor farmers. This approach is not focused solely on information delivery, rather a two-way exchange. In addition to access to communications and infrastructure (via the Internet and mobile phone network), users can access and act upon data from their environment via the sensor network, and also send data both manually and automatically over the same infrastructure. This approach emerged from our initial consultations with the communities, as they expressed the desire not just for information but to share their data with other communities and the wider world.

3. SITES SURVEY

3.1 Kiangwachi

Kiangwachi is located in the central highland area, close to Mount Kenya (Africa’s second highest peak. The land is generally lush, green and fertile, and rainfall is regular, although some degradation has been caused by deforestation. There are large well-watered fields of maize, beans, wheat and vegetables and the soil is rich, dark red-brown and moist. Water is available locally, although petrol pumps are used to irrigate the crops.

The group of farmers we met were newly formed and located on the slopes of Mount Kenya in the central area. The villagers belong to the Kikuyu ethnic group but many speak English fluently. Most have between two and five acres of land on which they grow mixed crops of bananas, maize, French beans and baby corn. They engage in various farming activities to minimise the risk of a falling market or low harvest, and are not afraid to learn and try new things to improve their practice at any cost. These farmers expressed the need to know when to plant, when to harvest, and how to obtain good prices for their produce.

Rainfall is fairly consistent in the area. A river provides sufficient water for all nearby farmers; it never dries up and its current is fairly strong. However, not all are making the best use of water. Most farmers use motor pumps to transport water to farms. The land needs to be irrigated two to three times a week during the dry season, and irrigating a plot of two acres requires up to six litres of fuel; this can cost around 1,500KES (about $21USD) per day. Poorer farmers do not collect rainwater for re-use, as in Figure 1.

Figure 1. Rainwater collection tank.

Few properties have electricity, but most members have mobile phones which can be charged at the local town or by neighbours with access to electricity. Some villagers have solar panels which supply small amounts of power. The nearest fixed access to the Internet is in the town 20 km away.

3.2 Kambu

Kambu, by contrast, is a small town in the south of Kenya, halfway between Nairobi and Mombassa. The area faces severe challenges including drought and environmental degradation, as seen in Figure 2. It is claimed that given enough rainfall, crops grow much faster in Kambu then in most other regions; however, drastic climate changes have included the delayed onset of rainfall, unpredictable weather patterns, and poor rainfall distribution. As a result the area around Kambu is one of the poorest parts of Kenya.

There is no sign of running water in the villages; tap water can be found only in town centres. In fact, water is so precious in this area that it costs more than fuel for motors. As a result, local farmers we visited do not irrigate or use other means to water their main crops, which include maize, millet, sweet potatoes, pumpkin, beans, pigeon peas, greens, arrow root, cassava and yam. Water needs to be pumped using expensive petrol, or stored in tanks to provide gravity feeds. The nearest spring water is 30 km away.

Figure 2. Typical dry field conditions in Kambu.

Villagers blame the lack of water for their condition and the decline of agriculture. Most do not use mixed farming which ensures food availability in all seasons. Consequently, two out of three families experience food shortages. Between November and June there is plenty of food; then there is nothing. Only those who plan well get through the year painlessly. People do not farm to sell but only to consume, so they are left with no food and no money to buy food in the dry season. Improved seeds for dry land, though they exist, are not affordable to even the most successful farmers here. There is a clear lack of knowledge of well-planned, safer farming.

Low literacy levels (about 50 percent) have exacerbated environmental degradation through destructive practices such as charcoal burning, sand harvesting, overstocking and overgrazing. High population growth has meant cutting down trees for settlement and charcoal burning. Thus this creates a destructive cycle as the land loses water and wild animals, and the soil erodes further.

The farmers have indigenous knowledge, but expressed the need for better farming knowledge. Since the land is dry, several Non-Governmental Organisations (NGOs) have shown interest and worked with the community, but these efforts have not always been successful. The farmers — particularly older women — continue to work the land, as this is seen as a source of independence and economic security. The group we met is well-organized and self-motivated. A system of national extension officers has supported local farmers, but this facility has been withdrawn recently.

3.3 Initial findings

Initial field research was carried out in 2007 in the both communities by researchers from the University of Nairobi and Thames Valley University who are versed to some extent in the local languages and cultures. The methods included evaluations of interfaces of existing mobile devices such as phones, cameras and iPods; a structured survey of technology usage and coverage; and ethnographic study of local agricultural and community practices among 36 adult farmers in Kambu, and 40 in Kiangwachi; in both communities the farmers are part of agricultural self-help groups. We discovered the following, commonalities:

- There is a lack of familiarity with digital technology such that most have no clear mental model of how many technologies work or how they could be useful.

- Agricultural knowledge sharing issues frequently come up. Since the communities practice mixed farming based on interest, it becomes difficult to find out everything to know about a crop before investing in it. Consequently, halfway through the process, farmers sometimes realize they do not have all the knowledge required.
- Literate and older professionals tend to record their farming activities (when planted, when to harvest, how much harvested, how much spent of particular crops, etc.). Others do not keep records and thus often cannot tell if they are operating at a profit or loss.
- Less than 10 percent of villagers comfortably read English. However, 50 percent in one village, and 90 percent in the other, indicate they have used, and like using, computers. On the other hand, less than 20 percent have heard of email or the Internet.
- Nearly all, however, have access to mobile phones. This use is almost exclusively for voice, not text. 85 percent are not aware of money transfer and other mobile services.
- Users indicate a preference in user interfaces for color, iconic legends, text, and representational icons, in that order. Numeric keypad interfaces fare poorly, implying a dislike for current mobile phone interfaces.

In their irrigation and farming practices, both groups practice low-risk strategies, but the less resource-poor area is more likely to experiment with new crops or new technologies. Given that water is precious in one area, and could be better utilised in the other, any technological intervention should seek to maximise the impact of irrigation while minimizing water intake. Monitoring of the environment and assessing the impact of temporal and spatial variability would seem to be a productive strategy. Both groups desire a two-way sharing of data and a simple means of recording their farming activities.

We originally set out to do participatory design directly with individual members of the communities. However, based on a Hofstede [2001] analysis, confirmed by our initial fieldwork and anecdotal evidence, we have learned that although the communities tend to be collective in nature, they have strong power structures in which organizations and institutions with formal boundaries and hierarchical structures are recognized and accepted. Therefore, the hardware is initially in the care of prominent individuals in the community, but it is important that it be viewed as collectively owned.

Thus it is more useful not to consider individual users but instead community-centered design. For example, mobile phone sharing is common. While technologically users are more comfortable with phones than computers, literacy patterns and usage suggests ruling out text-based communication such as SMS.

From the data collected, we developed the following use cases for a hybrid sensor network/mobile phone system:

- Calibration: A wireless sensor network must be calibrated when first deployed, and this should be simple and very clear, communicated by simple visual and/or aural means.
- Alert: When a parameter reaches a specified threshold, the system should notify the farmer, by similar means, locally or over the mobile phone network.
- Irrigation support: The system should give timely feedback to monitor different irrigation strategies as they are tested.
- Water requirements: If a computer model can be built for particular crops and local conditions, predictions could be made about water requirements and strategies.

4. SYSTEM ARCHITECTURE

From the data collected and use cases constructed, the following hybrid system has been specified. This will be deployed first at a test site in the UK, then in a demonstration plot in each village. In consultation with the communities, French beans will be grown in Kiangwachi, and in Kambu, watermelons will be grown along with Jatropha which has been selected by the community for its potential as a biofuel. Biofuels have become a controversial topic in recent months and have a complex relationship to sustainability and climate change: High oil prices make biofuels such as Jatropha attractive alternatives, but high food prices mean that land which could be allocated to food production may be diverted to biofuels, as has happened in the U.S. thanks to heavy subsidies. The Kambu farmers are aware of the increased global demand for biofuels and therefore see Jatropha as a potential cash crop; however their interest at this time is merely experimental, since their first priority is growing adequate food crops in their harsh climate.

4.1 Sensor network topology

The network topology consists of collaborative sensor node designs that self-organise, exploiting small-world principles inspired by social and biological networks, to ensure that the distance between nodes remains small as the network scales. The topology also makes use of advances in routing and information theory, including an efficient network architecture that achieves full connectivity with minimum edges.

Due to the particularities of deploying wireless sensor networks for agriculture in such a resource-limited context, new research challenges must be addressed. For instance the sustainability of the network requires minimal hardware cost and, ultimately, autonomous operation, since no technical expertise will be available for maintenance. This, along with the fact that deployment areas are typically large, requires scarce deployment of nodes in a large field. This contrasts to the conventional 'dense' deployment of sensor nodes which is a typical assumption in sensor networks designs [Akyildiz et al, 2002]. Consequently the benefit of using node scheduling approaches for power conservation is highly limited. Furthermore, the radio range of the nodes should be large enough to guarantee connectivity. This, along with a consequent requirement for relatively higher sampling rates, puts a further burden on the power budget of the nodes.

To address this challenge, the inherent parameter-homogeneity of a typical agricultural field is taken into account. Using pre-defined homogeneous zones [Camilli et al, 2007; Konstantinos et al, 2007] a zone-based topology management algorithm has been developed to project the network topology on the field homogeneity map. This optimizes coverage of the scarce node deployment while avoiding unneeded redundancy. Additional inter-zone nodes are also considered to account for fault tolerance and reliability.

Another special design challenge is the reliability of the telecommunications infrastructure in such a remote community. Typically these areas are classified as unprofitable by telecom operators, hence limited capacity is allocated for them, especially for data communications (e.g., GPRS). Consequently the backbone link for the sensor network is highly unstable in terms of availability, bandwidth and quality. To address this challenge we are developing appropriate architectures and protocols, initially inspired by the Delay Tolerant Networking (DTN) concept [Ho and Fall, 2004]. These include a multi-sink architecture where the sensed data is aggregated in several nodes, as opposed to a single sink. These sink nodes are located along the edge of the field for automatic data logging when handheld devices pass by. This provides an alternative means of data collection.

Another ongoing effort is the development of a backbone/storage-aware routing protocol. The essential idea is that the sink(s) broadcast the backbone link status, along with the available memory capacity. Also the nodes broadcast their storage status. When the backbone link is not available and the storage capacity of the sink(s) is not appropriate, then the data will be routed within the nodes until circumstances change. The routing criteria would be balancing the overall 'storage space' of the network. To enable this, several storage management and asynchronous messaging approaches are considered.

Due to the power constraints in the field environment, new forms of power-aware routing of data are required in which the known locations of sensors aid routing so as to minimise the power needed. Routing heuristics are being developed to exploit minimum energy paths, and maximise the minimum power over all network nodes or avoid power drain at strategically positioned sensor nodes (e.g gateway/sink nodes). We define virtual node locations based on the power needed to reach them, rather than their geographic location, and derive appropriate routing algorithms. The goal is to achieve a successful balance between power consumption, acceptable field coverage and network connectivity while employing scarce deployment of sensor nodes. We are exploring power-save modes of operation in the sensor nodes, and studying the impact of additional power consumption during wake-up sequences, leading to optimised power conservation algorithms.

4.2 Sensing subsystem

Soil moisture (volumetric water content) and soil temperature are sensed directly using the Decagon ECH2O probes, with an accuracy of ±%3 without calibration.

Weather data such as ambient temperature, rainfall and humidity information could be collected from local weather stations. However, according to the World Meteorological Organisation, the collection of weather data in Africa has gotten worse as many of the automatic weather stations it helped set up have fallen into disrepair. Therefore we utilise on-board temperature, humidity and ambient light sensors.

Inspired by U.C. Berkeley's Mica Motes, the sensors are interfaced to an Atmel Atmega128L microcontroller, with 512K bytes of flash memory and 4K bytes of RAM.

4.3 Communication Subsystem

For the sensor network, IEEE 802.15.4 (ZigBee) compliant RF transceivers are used for intra-network communications between sensor nodes. Bluetooth is also used by sink node(s) to broadcast data to any passing Bluetooth-enabled device. In this way, people (more precisely handheld Bluetooth-enabled devices) are treated as mobile data loggers in the network. Data is also automatically uploaded by sink/gateway node(s) via GPRS data service, since this is the only current option for network connectivity in the regions in which we are working. We are investigating embedded GPRS modules such as the Libelium GPRS/GPS module. Data could also be sent via SMS using an SMS gateway such as Clickatell which is used for mobile phone application development by the University of Nairobi. However, this is not a priority for us given end users' reluctance to use SMS due to literacy levels and cost.

GPRS is also used in the villages for Internet access, and the initial resource kit sent to the two villages included a laptop with GPRS modem and solar charging kit. The cost of GPRS data service is initially paid by UK-based project partners, and we are investigating sustainable solutions for providing ongoing service. We are also investigating WiMax technology for long-distance (up to 50km) communication [see Dekleva et al, 2007].

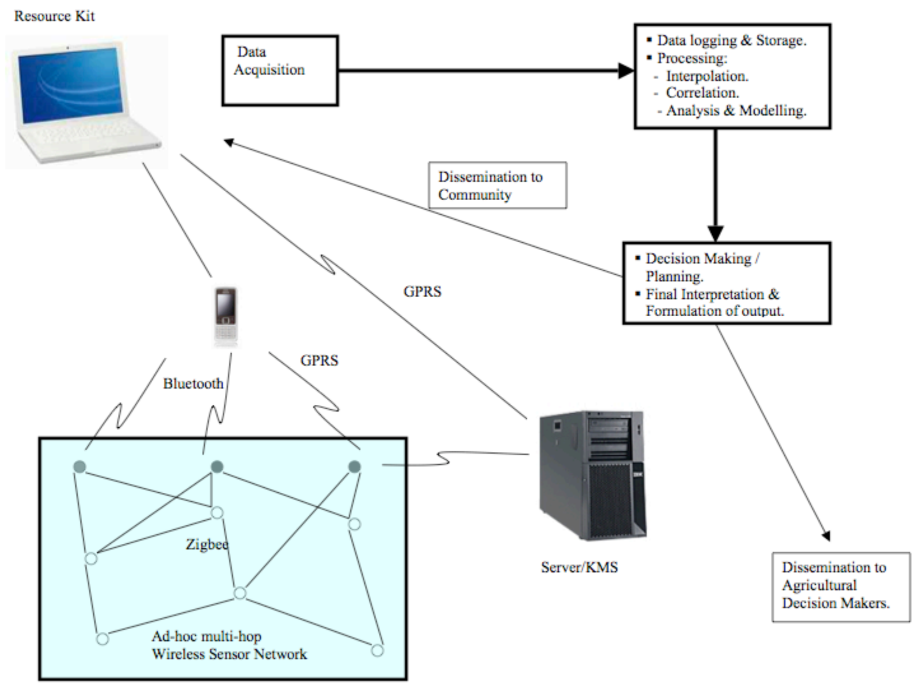

Figure 3. System architecture

4.4 Processing

Proper data processing is a critical element for the success of using technology in developing world applications, especially when considering a sensor-based system [Wang et al, 2006]. In order to build crop models, we need local weather data (including solar radiation, air temp, rainfall). Long-term records do not exist for the regions we are working in, so this data needs to be collected over time. We also need to record soil data, including depth, composition, density, carbon level, pH, aluminium, root abundance. Some crop-specific data can be gathered from existing crop modelling software such as APSIM [Keating et al, 2003]. However, packages such as these, having been created in and for the developing world, have usability issues in our context.

The sensor network can then help evaluate different water conservation measures delivered by the KMS. As mentioned previously, this system is a two-way exchange of information. A crop model which both informs and is informed by the sensor network can be complemented by an agricultural database for end users such as Infonet Biovision (www.infonet-biovision.org).

So for example, a user in one village can input a particular water management strategy to the KMS using a GPRS-enabled phone; this can be accessed and used by a user in another village. The sensor network there can automatically log the results of the intervention and feed them back into the KMS, making comparison possible between sites and over time.

Because users are treated as ‘mobile nodes’ in the system, user-generated data such as photos, text and audio interpretations can be uploaded and matched with sensor data. For example, a photo of the status of a particular crop can be matched with sensor data on that crop, providing a secondnary and more readily understandable ‘ground truth evaluation’ of the sensor data. As a later step, the feedback loop could be closed so that user-generated data documenting the results of an intervention can feed back to the sensor network to automatically generate water management strategies.

4.5 Data access subsystem

Data is collected, processed and served by the KMS which is built with the open-source Drupal content management system. Drupal Mobile is used to serve content to mobile devices. Usability is key, since as stated previously, many users have no ICT knowledge. Therefore real-time and archived data must be presented using simple interfaces. This development is a joint effort between the University of Nairobi which is undertaking mobile application and interface development, the University of Bradford which is working on server setup and administration, and the London Knowledge Lab which focuses on educational end use. The KMS is described in greater detail in Wirastuti, et al [2008].

The system is initially tested in a deployment at Kew Gardens, a large public botanic garden in London. This deployment will include interpretative data made available to the public both over the web and via Bluetooth broadcast locally in two test plots in which similar crops are grown.

4.6 Power subsystem

Individual nodes are battery-powered. A two-month typical battery life-time, for soil moisture sensing via sensor network, has been reported by Panchard et al [2006]. By optimizing the network design, as described previously, we intend to enable the batteries to cover, at least, the whole cropping season. Solar charging and power scavenging techniques are being investigated. A comparison between sites is planned, since for example UK has longer daylight hours during the summer, but with the sun at a more oblique angle.

5. CONCLUSION AND NEXT STEPS

We deploy technologies in a phased manner and with targeted activities designed to familiarize users with the technologies and the concepts underlying them. First, basic computing and network access is introduced; then, networking activities are carried out on mobile devices; then the sensor network adds the dimension of automatic data collection and ubiquitous computing. The basic computing and access resource kit, including laptop, GPRS modem and solar charging kit has been delivered to the communities in February 2008 and successfully received and tested. Mobile application development is being undertaken by the University of Nairobi and UK partners, and is expected to be deployed in the Spring. Meanwhile, the sensor network is to be deployed at Kew Gardens in March; after testing throughout the UK growing season it will be deployed in Kenya in the Autumn for the growing season there.

For ongoing sustainability we are working to keep costs down, and maintain agile development methods which are adaptable to change. Development is distributed and open source technologies are used to the extent possible. The communities continue to be involved in the design and evaluation at each stage.

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REFERENCES

Akyildiz , I. F., W. Su , Y. Sankarasubramaniam , E. Cayirci, Wireless sensor networks: A survey, *Computer Networks: The International Journal of Computer and Telecommunications Networking* 38(4), 393-422, 2002.

Camilli, A., C.E. Cugnasca, A.M. Saraiva, A.R. Hirakawa and P.L.P Correa, From wireless sensors to field mapping: Anatomy of an application for precision agriculture, Computers and Electronics in Agriculture 58(1), 25-36, 2007.

Dekleva, S., J.P. Shim, U. Varshney and G. Knoerzer, Evolution and emerging issues in mobile wireless networks, *Communications of the ACM* 50(6), 38-43, 2007.

Economist, The. Kenya: Going up or down?, *Economist* (UK Edition) 9 June 2007. (http://www.economist.com/world/africa/displaystory.cfm?story_id=9304146)

Hartman, K., K. London, R. Bray and R. Faludi, Botanicalls: The plants have your number, http://www.botanicalls.com, 2006.

Ho, M. and K. Fall. Poster: Delay tolerant networking for sensor networks, 1st IEEE Conf. on Sensor and Ad Hoc Communications and Networks, 2004.

Hofstede, G., *Culture's Consequences: Comparing Values, Behaviors, Institutions, and Organizations Across Nations*. Thousand Oaks CA: Sage Pubs, 2001.

Konstantinos, K. A. Xenakis, P. Kikiras and G. Stamoulis, Topology optimization in wireless sensor networks for precision agriculture applications, Proc. Int'l Conf. on Sensor Technologies and Applications, 526-530, 2007.

Panchard, J., S. Rao, T.V. Prabhakar, H.S. Jamadagni and J-P Hubaux, COMMON-Sense Net: Improved water management for resource-poor farmers via sensor networks, Int'l Conf. on Information and Communication Technologies and Development, 2006.

Wang, N., N. Zhang and M. Wang, Wireless sensors in agriculture and food industry: Recent developments and future perspective, *Comput. Electron. Agric*. 50, 1-14, 2006.

Wirastuti, D., R. Luckin, R.E. Sheriff, K. Walker, J. Underwood, and L. Dunckley, Development of a knowledge management system integrated with local communication channels and knowledge management initiatives for Kenyan rural farming, 5th Int'l Conf. on Wireless, Mobile and Ubiquitous Technologies in Education. Beijing, 2008.