Digital Villages: A Data-Driven Approach to Precision Agriculture in Small Farms

Ram Fishman[1], Moushumi Ghosh[2], Amit Mishra[2], Shmuel Shomrat[3], Meshi Laks[1], Roy Mayer[1], Aakash Jog[4], Eyal Ben Dor[3] and Yosi Shacham-Diamand[1,4]

[1]*School of Public Policy, Faculty of Social Sciences, Tel Aviv University, Tel Aviv, Israel*
[2]*TAU/TIET Food Security CoE, Thapar Institute of Engineering and Technology, Patiala, Punjab, India*
[3]*Remote Sensing Lab, Faculty of Exact Sciences, Tel Aviv University, Tel Aviv, Israel*
[4]*School of EE, Faculty of Engineering, Tel Aviv University, Tel Aviv, Israel*

Keywords: Precision Agriculture, Sensor Network, Field-deployable Sensors, Satellite Multispectral Imaging.

Abstract: An approach for system monitoring of smallholder farms. The system will be based on low-cost mobile units (i.e. IoTs, phones) collecting and transmitting data directly from the farms. The IoT information will be merged with available and free access satellite data to form near real-time thematic images to the end-users. It will serve people with low technical literacy who are working with smallholders in developing countries. The novelty of using an integrated interdisciplinary behavioral-technological approach that builds on our respective disciplinary expertise, and the ability to pilot and implement at scale through partnerships, on the ground, allowing gaining new insights into smallholder cultivation and revolutionizing agricultural extension in the developing world. To achieve that goal of Holistic Integrated Precision Agriculture Network (HIPAN) three networks have been established in experimental farms in India: wireless network for "on-the-ground" sensing, virtual network with satellite multispectral imaging-based data and social network collecting the farmers' inputs. The three networks are fused together and the data is processed using a cloud supported data analysis; the results are visually transferred to the farmers as well as to organizations and companies for their benefit.

1 INTRODUCTION

The concept of the digital village provides modern technology-based solutions for intelligent crop farming. It assists smart irrigation (Atieno, L. V., & Moturi, C. A. 2014, Manami, A., Harshitha, H., & Mohan, R., 2018, October), efficient electricity supply (Mackenzie, D., 2019), E-healthcare (Ella, S., & Andari, R. N. (2018, October) water quality monitoring and management (Manoharan, A. M., & Rathinasabapathy, V. 2018). Digitally supported precision agriculture will improve living conditions in rural areas and reduce population migration to urban areas (Shukla, P. Y., 2016). Precision agriculture is a wide field the includes identifying field phenotyping (Großkinsky, D. K et al., 2015), manually or assisted by robotics (R Shamshiri et al, 2018), data collection and transfer using information and communication (ICT) methods (Koutsouris, A. 2010, Griffith, C., 2013), and data analysis using various methods, for example, deep learning and artificial intelligence (Wolfert, S. 2017, Kamilaris, 2017). Recent papers are discussing the issue of precision agriculture in the rural areas (Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017), Wolf, S. A., & Wood, S. D. 1997 and Salemink, K., Strijker, D., & Bosworth, G. 2017) highlight its importance.

We propose to develop, field-test and implement a novel, integrated approach to monitoring smallholder farms that is based on the rapidly increasing ability of low-cost mobile phones and sensing devices to collect and transmit data directly from farms. We will adopt these technologies to be usable at scale by extension agents of low technical literacy who are working with smallholders in developing countries.

The novelty of using an integrated interdisciplinary behavioral-technological approach that builds on our respective disciplinary expertise, and the ability to pilot and implement at scale through partnerships, on the ground, in developing countries could give our approach the potential to gain new

Fishman, R., Ghosh, M., Mishra, A., Shomrat, S., Laks, M., Mayer, R., Jog, A., Ben Dor, E. and Shacham-Diamand, Y.
Digital Villages: A Data-Driven Approach to Precision Agriculture in Small Farms.
DOI: 10.5220/0009373101610166
In *Proceedings of the 9th International Conference on Sensor Networks (SENSORNETS 2020)*, pages 161-166
ISBN: 978-989-758-403-9; ISSN: 2184-4380

research insight into smallholder cultivation and to revolutionize agricultural extension in the developing world. Innovative sensing technologies are already widely used in industrialized farms, and there is growing interest in applying them in developing countries. However, our approach stands out in:

(1) A human-centered design process, in the field of "*crowd sourcing or citizen science* , of a tool that is useable by extension agents with limited technical literacy and will overcome social, cultural, economic (cost) and behavioral limitations to the applicability, at scale.

(2) Integrating data on farmers (crop assessments, decisions, practices, investments and sales) and crops (biophysical data gathered from sensors). To date, both types of data remain disparate, severely limiting inter-disciplinary research.

An ability to pilot, adapt and deploy the same product at the global scale through existing partnerships with strong partners in India, Nepal and Kenya.

2 THE DIGITAL VILLAGE

The digital village project (Fig. 1) includes several components:

- Development of the digital platform.
- Integration and development of new and existing sensing technologies.
- Piloting and adapting in real field conditions in ten villages in Punjab.
- Data analysis to derive novel research insights on smallholder agriculture.

Figure 1: The digital village concept (Illustration).

The idea is to develop a holistic remote and local sensing methods using both spectral imaging and Micro and Nano sensor based digitalized information and communication technology (ICT) for the farmer use, taking data from the farmland to the cloud providing accurate near-real time to the logistics analysis. This kind of a system, as well as other many options, are tailored to the huge varieties of agriculture. This approach, which we may call, Holistic (or Wireless) Integrated Precision Agriculture Network (HIPAN or WIPAN), can be based on existing cellular networks as well as on proprietary networks forming an "Internet of Things" network for agriculture and food.

The project methodology (Fig. 2) encompasses data display for the respective field parameters: soil properties (pH, texture, temperature, organic matter, nitrogen, salinity, phosphorous content, pesticides and water properties), plant parameters, pre-planting & post-planting, irrigation requirements and post harvesting parameters and vegetation stress (i.e. color, shape, volatiles etc.). The proposed technology is being developed to present current status as well as to predict possible scenarios such as dehydration, transpiration heat (or cold) damage or pathogen attacks based on the change detected using Micro Systems Technologies, i.e. sensors, micro-electro-mechanical systems (MEMS) supported by very large scale (VLSI) application-specific integrated circuits (ASIC). Close and far remote sensing means (from the field, air and space domains) is being developed to assess soil chemical and physical attributes using simple and easy to use methodologies. Libraries of spectral signals (LSS) resulted from the outcrop of the former activity are being established over the cloud. The LSS is processed by using deep learning approach yielding recommendations to the farmers regarding the best ways to maximize field production on a local basis.

Predicted attacks can be verified using bio-signals taken from the plant leaves, stem roots or sap. Based on that, the pesticide and dosage could be decided and displayed digitally for the respective field and crop. This could help the farmer in various avenues providing the analysis results from the lab to the field directly for the farmers' use. It can also help the government synchronizing their activity taking care of stress and attacks appearing in numerous places. The MEMS-based sensor will require data analysis for the respective crop and field area, which could be processed to prepare the standard bands. Within the context of Indian agriculture practices, the proposed technology offers an advantage in both the status monitoring collecting data for both short- and long-range status report and also on the response strategy.

The Digital village environment includes both microelectronics-based sensors and networks and hyper and multispectral imaging data. The information is typically in the visible and near-infrared parts of the spectrum. The reflected and emitted light provides information about the soil and plants' chemical and physical status. This information is used as a proxy for wet chemistry analyses of both soil and vegetation and can be used from drones and/or free access satellite data. Information such as visible change due to drought, nutrient deficiency, pathogens, weeds or pests can be processed rapidly providing the farmer early warning regarding the crop yield or information about maturation and harvest readiness. This information has a high economic value.

There are a few challenges in hyperspectral imaging: a) identifying the signal. i.e. identifying its location and separating it from the noise, b) taking care of its high dimensionality, i.e. every vector data has many components generated by the imaged bands, and c) generating "big data" and "deep learning" algorithms analyzing the images.

The digital village uses databases as well as algorithms, for their analysis. A Soil Spectral Library (SSL which is the LSS of soil) for Punjab is being constructed in order to foster precise monitoring of the soil's properties in the field for improved agriculture practices without being dependent on an extensive laboratory-based labor. Second, to develop machine learning algorithms for hyperspectral analysis; The goal is to develop the base for the proper algorithms making the Internet Of Things and the associated multispectral analysis useful. For example, deep learning and machine learning algorithms can be useful to automate the overall system reducing the need for manual intervention providing the farmer with the desired information faster and in a more reliable and cost-effective way. The data is processed externally whereas the final product, the thematic maps, with practical instructions. will be uploaded and delivered to the farmer's mobile screen.

The model incorporates novel concepts such as Deep learning and the "Intelligent cloud" introducing concepts such as smart gateways and machine learning in the cloud leveraging the capabilities of the cloud. The cloud is getting more intelligent and is capable to learn from the data stored in the cloud. It can make predictions and analyze the situation better. This platform is capable to perform tasks accurately and efficiently. Artificial intelligence systems are working better on cloud computing servers. This is due to the low cost of operations, better reliability, and the availability of huge processing power analyzing a large amount of data. The database and algorithms are being written in a modular way and in open architectures.

The IoT network includes the sensors and the gateway in a mesh architecture. The overall system is adaptive, flexible and smart. It has few tasks: a) taking care of the data, filtering it, storing it and transmitting it, b) providing general information such as position and time, c) monitoring system performance generating a status report, d) checking the sensors deciding what to do when a sensor fails, and e) providing the desired cybersecurity layers. Fog, co-located with the Smart Gateway can perform the pre-processing tasks generating interrupts and status report to the system on the way to the cloud. We assume that only pre-processed data is required to be stored in the cloud, providing relatively low latency communication and more context-awareness.

3 OVERVIEW

The research includes the following steps where the whole concept is being evaluated:

1. Run a feasibility study defining the desired crop where the holistic approach of IoT + smart gateways and novel algorithms (i.e. deep learning, AI, etc.) is being applied.
2. Run a feasibility study defining the key parameters required for that crop (including soil water and climate), prioritized them and define the economic value of the HIPAN approach: the intrinsic contribution to the overall yield, the extrinsic impact on the marketplace up to the customer taking into consideration the whole food chain
3. Assess the social impact of the HIPAN approach including the resources needed for training, application and management.
4. Assess the potential economic value building industry in India based on the HIPAN approach, both national and international.
5. Identifying a national (or international) partner for large scale manufacturing.

4 METHODOLOGY

The Digital village methodology takes action from the plant to the cloud using wireless networks of sensors, gateways, ground and satellite multispectral data and social networks. (Fig. 2)

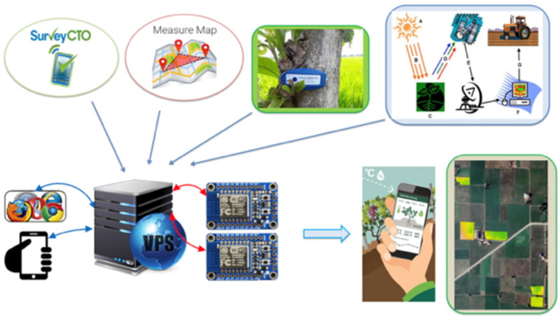

Figure 2: The digital village methodology.

A key strength of our approach lies in the ability to continuously pilot, evaluate and adapt the platform by leveraging on the partnerships between the universities, the research institutes and the farmers. Agricultural extension agents will be employed in the pilot “digital village” getting careful training by faculty and students who are supervising the fieldwork. The agents, supported by students, collect “non-digital” data complementing the “digital” data from the sensors.

5 DATA ANALYSIS AND EVALUATION OF PILOTS

After completion of developing the prototype, we will implement data collection on the scale of a few hundred farmers in the three field sites over the course of one agricultural annual cycle. We demonstrate the potential of our approach which includes also an assessment of the correlation between farmers’ perceptions of crop conditions and actual conditions captured by sensing technologies, and whether any differences between perceived and actual status may lead farmers to respond in agronomically inappropriate ways. To date, hardly anything is known about those questions.

5.1 Sensor Networks

The sensor periodically measures physical and chemical parameters of field such as temperature, relative humidity, pH value etc. Those sensors are placed in selected locations in the field and configured in a mesh topology. The Sensor Gateway (SG) is designed to transmit all the data collected by sensors throughout the monitored site to the communication server and through it - to the Web application. The SG acts as an access point for sensors, and other wireless sensors. The SG is the "root node" of the sensors network, where all the measurements are uploaded to. The SG also connects to the communication server, further uploading measurements from the sensors through an internet connection, whether cellular or LAN based. The data is merged with remote sensing information from drones and satellites.

5.2 Satellite based Networks

For that purpose, field, drone and satellite sensors will be used covering the optical range (0.4-2.5nm) as well in some parts we might use imager covering the “thermal” long-wavelength infrared (LIR) range (7.5-11nm). The optical sensors are multi and hyperspectral ones for field assessment operating either as a single point measurement or in the imaging mode. The point spectrometer is used to construct the SSL and the imaging for establishing the thematic maps on a spatial basis. To that end, we will use sensors on drones (for local monitoring) and from satellites (e.g. LANDSAT and Sentinel-2) that characterize by an effective temporal coverage. We also construct the foundation to process the forthcoming hyperspectral sensors from orbit that will be available soon to expert users.

5.3 Social Networks

In parallel to the technology-based networks social networks are also established verifying the actual status of various parameters in the field as seen via the human perception of the farmers and other human factors. This information is used to adjust the overall usability of this approach for the benefit of the farmers and the a whole agricultural system as governed by local and state government and non-government organizations.

6 HOLISTIC INTEGRATED PRECISION AGRICULTURE NETWORK (HIPAN)

The HIPAN is actually an Internet of Things (IoT) system tailored for agriculture. As such it is composed of the following units:

6.1 The Hardware Unit

6.1.1 The End Unit at the Field

1. Sensor/actuator,
2. Front end electronics – analogue unit, analogue to digital converter (ADC),

3. Digital unit – processor, memory,
4. Communication unit,
5. Power supply – power harvester, distribution and monitoring unit.

6.1.2 Network Gates

Smart gateways, there are few options depending on the network type (i.e. star, mesh) and how we collect the data. We currently use the following approach:

1. For connecting the sensors between themselves and the gate we use the amateur band at 433 MHz (non-licensed band),
2. For connecting to the gateways an outside we use licensed bands (i.e. WIFI, Cellular, etc.).

6.1.3 Multispectral Imaging Units

1. A full range ASD spectrometer (400-2500nm) (or equivalent) as the motherhood sensor with a point spectrometer of Ocean Optics (400-2500nm) as a daughter's sensor shall be required to build the LSS.
2. Assemblies to Cellphone cameras for the standard measurement of the soil and crop images.
3. A gate to ESA and NASA data satellite data basis.
4. SoilPRo® assembly for spectral measurement of the undisturbed soil surface.

6.2 The Software Unit

6.2.1 Communication Protocols

Following is the list of principles used in the digital village:

1. Connecting he sensors between themselves and the gate using the amateur band at 433 MHz (non-licensed or amateur band),
2. Connecting to the gateways and to the outside using licensed bands (i.e. Wi-Fi, Cellular, etc.)
3. Data processing algorithms: improving the signal to noise ratio, data compression, spectral based model for a given attribute etc.
4. Data security protocols – RSA, blockchain etc.
5. Data analysis algorithms - preprocessing to identify critical problems before sending the data to the cloud for further analysis,
6. General software: control, monitoring and uploading / refreshing protocols. Data transfer from the field to the cloud and back

6.2.2 Additional Units

Signal processing, data encryption etc.

6.3 Auxiliary Outcome

The digital village system provides the following tools:

- Chemical and physical analytical data of soil and plants using traditional laboratory methods Establishing a SSL for Punjab. Within this action, soil samples from all over Punjab will be collected and documented in the field under a common protocol and achieve in one place for future analyses. The soil will undergo traditional wet chemistry analysis as well as a standard soil spectral measurement. This process is adaptive: as much more samples will be collected, the SSL will be improved. In the long term, the Punjab SSL will be merged with the World SSL.
- Extracting spectral base models for any attribute by deep learning approach (first attributes are: Organic Matter, Salinity, Soil water retention, pH, and Texture)
- Developing a simple field apparatus for the farmer. Developing the Satellite base application; Applying the SSL on the current and future satellite sensors.

7 CONCLUSIONS

This "digital village" concept combines the Internet of Things concept with satellite-based information generating a localized low-cost source of data and analysis tools for the farmers. It is expected to reduce costs significantly in precision agriculture monitoring allowing small farm, which is the most abundant concept in underdeveloped and developing countries, to succeed. However, the digital village concept, where modern digital media is harnessed for the benefit of the farmer requires significant research and tune-ups. We describe here a preliminary study being carried in India under the Tel Aviv University/Thapar Institute of Engineering and Technology Food Security Center of Excellence (T^2FSSoC). This project is paving the way to more specific applications with very specific targets:

- The application: variety on the field, variety in the soil, plant or animal, post harvesting and storage, transport and delivery etc.
- The technology: The system complexity, the huge number of possible sensors, IoT systems, communication protocols etc.

Therefore, here are a few important objectives:

- The most important agriculture products to apply the HIPAN approach,

- The most successful technologies to be applied,
- Define the test case and building a prototype, testing its feasibility in the farm.
- Define the best practices to engage farmers with the HIPAN approach

In future phases of this research, we will seek to scale up gradually to additional sites in Punjab and India and conduct a "Big Data" analysis to derive novel research insights on smallholder agriculture. We will also conduct a randomized evaluation of the impacts of the recommendations on productivity.

ACKNOWLEDGEMENTS

Thanks to the TAU/TiET Food Security Center of Excellence grant for the "Digital village" project, 2019. This research was partially supported by the Israel Science Foundation (grant no. 1616/17). We would like to acknowledge the Boris Mints Institute for Strategic Policy Solutions to Global Challenges, the Department of Public Policy and the Manna Centre for Food Security, Tel Aviv University for their support under the program "Plant based heat stress whole-cell-biosensor" (grant no. 590351) 2017. Also thanks to the Boris Mints Institute for their support of the NITSAN Sustainable development laboratory. Finally, thanks to our industrial partners: Cartasense Inc. and Unispectral Inc. for supporting the project infrastructure

REFERENCES

Atieno, L. V., & Moturi, C. A. (2014). Implementation of Digital Village Projects in Developing Countries-Case of Kenya. *British J. of Applied Science & Technology*, *4*(5), 793.

Ella, S., & Andari, R. N. (2018, October). Developing a Smart Village Model for Village Development in Indonesia. In *2018 International Conference on ICT for Smart Society (ICISS)* (pp. 1-6). IEEE.

Griffith, C., Heydon, G., Lamb, D., Lefort, L., Taylor, K., Trotter, M., & Wark, T. (2013). Smart Farming: Leveraging the impact of broadband and the digital economy. *New England: CSIRO and University of New England*.

Großkinsky, D. K., Pieruschka, R., Svensgaard, J., Rascher, U., Christensen, S., Schurr, U., & Roitsch, T. (2015). Phenotyping in the fields: dissecting the genetics of quantitative traits and digital farming. *New Phytologist*, *207*(4), 950-952.

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture*, *143*, 23-37.

Koutsouris, A. (2010, July). The emergence of the intra-rural digital divide: A critical review of the adoption of ICTs in rural areas and the farming community. In *9th European IFSA Symposium* (Vol. 4, No. 7).

Mackenzie, D. (2019). IEEE Smart Village: Sustainable Development Is a Global Mission. *IEEE Systems, Man, and Cybernetics Magazine*, *5*(3), 39-41.

Manami, A., Harshitha, H., & Mohan, R. (2018, October). IoT based Smart Village. In *TENCON 2018-2018 IEEE Region 10 Conference* (pp. 1219-1223). IEEE.

Manoharan, A. M., & Rathinasabapathy, V. (2018, August). Smart Water Quality Monitoring and Metering Using Lora for Smart Villages. In *2018 2nd International Conference on Smart Grid and Smart Cities (ICSGSC)* (pp. 57-61). IEEE.

Salemink, K., Strijker, D., & Bosworth, G. (2017). Rural development in the digital age: A systematic literature review on unequal ICT availability, adoption, and use in rural areas. *Journal of Rural Studies*, *54*, 360-371.

Shamshiri, R., Weltzien, C., Hameed, I. A., J Yule, I., E Grift, T., Balasundram, S. K., & Chowdhary, G. (2018). R&D in agricultural robotics: A perspective of digital farming.

Shukla, P. Y. (2016). The Indian smart village: Foundation for growing India. *International Journal of Applied Research*, *2*(3), 72-74.

Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017). Opinion: Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences*, *114*(24), 6148-6150.

Wolf, S. A., & Wood, S. D. (1997). Precision Farming: Environmental Legitimation, Commodification of Information, and Industrial Coordination 1. *Rural sociology*, *62*(2), 180-206.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming–a review. *Agricultural Systems*, *153*, 69-80.