Smart Farming in sub-Saharan Africa: Challenges and Opportunities

Pamela Abbott[1][a], Alessandro Checco[1][b] and Davide Polese[2][c]
[1]*Information School, The University of Sheffield, U.K.*
[2]*Istituto per la Microelettronica e Microsistemi, Consiglio Nazionale delle Ricerche, Roma, Italy*

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Abstract: Smallholder farmers provide the majority of food production in sub-Saharan Africa. They will be severely impacted by climate change, especially because they are dependent on rain-fed irrigation. We provide a summary of challenges and opportunities in designing smart farming infrastructure in this context. We observe that innovation in technology and knowledge production is necessary to increase the efficacy of water usage and land management. Such solutions must take into account the technological constraints and their regional variability to be able to provide sustainable and scalable solutions. Such solutions also need to embrace the notion of openness, encouraging collaborative endeavour and avoiding proprietary implementations.

1 INTRODUCTION

Whilst it has been acknowledged that smallholder farmers may be contributing to environmental degradation through unsustainable agricultural practices, it is increasingly recognised that they may also hold the key to alleviating these problems (IFAD, 2013). Smallholder farmers are thought to provide as much as 80% of food production in sub-Saharan Africa (Stewart et al., 2014). They are, however, vulnerable to environmental conditions presumably linked to climate change such as unpredictable variation in rainfall leading to droughts and floods (Morton, 2007). Disruption to these farming practices thus threaten food security due to the dependence on smallholders for food production in countries already deemed vulnerable to climate shocks (IPCC, 2014). Solutions that may address this issue and lead to more sustainable farming practices are difficult to envisage and implement not the least because of the complex environments in which smallholder farmers operate (Morton, 2007). Their own situation is complex, often perceived as marginalised and lacking adequate resources (IFAD, 2013), while national level policymaking around agriculture tries to find a balance between the rhetoric of sustainability and competing agendas of market-driven production (Beddington et al., 2012; Busingye, 2017).

Many of these smallholder farmers in sub-Saharan Africa are dependent on rain-fed irrigation to grow their crops (Nahayo et al. 2018; Kinda & Badolo, 2019), thus increasing their exposure to crop-yield risk. In Eastern Africa, estimates of yield reductions in some crops are as much as 72% (wheat) and 45% (maize, rice, soybean) projected by the end of the century (Adhikari et al., 2015). Farmer-led initiatives to increase the efficacy of water usage and land management are thus being investigated along with innovations in technology and knowledge production (Woodhouse et al., 2017). One such innovation has been dubbed ‘smart farming’, which is described as the application of Information and Communication technologies (ICTs) to agricultural production, especially more advanced forms of technology such as the Internet of Things (IoT) and artificial intelligence (AI) (Wolfert et al., 2017).

In the last decades, an intensive investigation has been developed in order to maximize crop production trying to reduce resource waste. To this purpose, a

[a] https://orcid.org/0000-0002-4680-0754
[b] https://orcid.org/0000-0002-0981-3409
[c] https://orcid.org/0000-0002-6332-5051

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new research line, called precise agriculture has been created (Liaghat et al., 2010; Brisco et al., 1998; Ge et al., 2011; Jawad et al., 2017). Many efforts have been done to improve the state of health of the crops, reduce the waste of water, and reduce fertilizer usage. In terms of the implemented crop monitoring infrastructure, the main goal has been to improve its durability and to reduce its power consumption. Nevertheless, the vast majority of past work had a tacit prerequisite: the possibility of using the latest developed technology; to have access to a modern networking infrastructure, to satellite data, and modern hardware to visualise and process the information. This prerequisite is not always true in sub-Saharan Africa, where precise agriculture has to face strict constraints in terms of the aforementioned dimensions. Moreover, open hardware and software practices (including in the licencing context) are fundamental to reduce the dependencies to external economic factors (e.g. royalties).

In this work, we will briefly describe the most pressing needs of sub-Saharan Africa agriculture, which technological constraints are in place, what solutions have been proposed and what could be improved.

The rest of the paper is structured as follows. In Section 2 we provide a summary of the literature in the field of smart agriculture, especially in the context of sub-Saharan Africa. In Section 3, we present the main technological constraints that should be considered when designing smart farming solutions in this context. In Section 4 we discuss what we learned and provide a summary of our vision for a smart farming solution in sub-Sahar Africa.

2 RELATED WORK

2.1 Smart Farming in sub-Saharan Africa

Some sub-Saharan African countries are already embracing and implementing agricultural policies around smart farming, e.g. in Rwanda (Musoni, 2020; MYICT, 2015). More common, though, are solutions that attempt to go beyond pilot projects to implement more sustainable solutions that are scalable. Hence, many ICT-related agricultural initiatives involve the use of mobile phones often integrated with Unstructured Supplementary Service Data (USSD) platforms for widespread usage and uptake (Wouters et al., 2009), since mobile telephony is one of the more widely available ICTs due to relatively high penetration rates in the sub-continent. Some examples we are aware of include Farm-SMS in Tanzania (Makoye, 2013) and the M'chikumbe project in Malawi (Palmer & Darabian, 2017). These types of solutions often attempt not only to push information towards farmer participants but to encourage other forms of information and knowledge sharing such as building communities around particular kinds of knowledge.

Figure 1: Map of Tanzania, Eastern Africa, highlighting the Dodoma district and Tabora region, in central and western Tanzania, respectively, where the Farm-SMS initiative is reported to be sited (image source: Perry-Castañeda Library Map Collection [PCLMC], 2016).

Key facts about Tanzania:

- **Population**: approx. 56 million (2018 est.)
- **Size**: approx. 947,303 km^2
- **GDP per capita**: $USD 3,574 (2019 est.)
- **HDI**: 0.529 (2019)
- **Agricultural sector**:
  - 24.5% GDP (2013 est.)
  - 85% of exports
  - Employs approx. 50% workforce
  - Largest food crop: maize

Source: https://en.wikipedia.org/wiki/Tanzania

According to Makoye (2013), the Farm-SMS initiative was founded in 2010 through a collaboration between the World Meteorological Organization (WMO) and the Tanzanian Meteorological Agancy (TMA). The pilot project has two sites, one located near Dodoma, the legislative capital of Tanzania in the central region of the country and the other in the Tabora region, both of which are reported to be drought-prone (see Figure 1). The service provided by Farm-SMS allows farmers in the region to receive real-time weather forecasts and tips from agricultural experts at a nearby research centre through SMS text messaging and emails. Farmers who participated in the pilot reported between 50% and 125% improvement in yields compared to traditional methods of forecasting the weather. It is unclear what is the current status of the project and whether it has had a sustainable impact beyond the pilot (some further information seems to be available via Tall et al., 2014).

The M'chikumbe project in Malawi (See Figure 2) was started in 2015 as a pilot project through collaborations with various international donor agencies, Airtel Malawi and Malawian government agricutlural services (Palmer & Darabian, 2017). According to these authors, the project gained siginficant support among its user base acquiring 400,000 users by December 2016. The service provides access to agricultural information and educational materials from both the agricultural extension services and partner content providers. SMS messaging and interactive voice recognition (IVR) through mobile technology underpin these services. In addition, a network of 'lead farmers' and other trusted information providers enable the spread of content to farmers. The report provides evidence of 'power users', those most actively engaged in the service, claiming increases in crop yields as a result of using the service (about 53% of those users). While it started as a pilot in 2015, the project is ongoing with services branching out into mobile money, which helps to keep the platform host, Airtel Malawi, on board. Further plans are being put into place to maintain the sustainability of the project.

Key facts about Malawi:

- **Population**: approx. 19 million (2020 est.)
- **Size**: approx. 118,484 km^2
- **GDP per capita**: $USD 1,234 (2019 est.)
- **HDI**: 0.483 (2019)
- **Agricultural sector**:
  - 27% GDP (2013 est.)
  - 90% of exports
  - 80% of population are subsistence farmers
  - Largest export crop: tobacco
  - Large food export crops: tea, sugar, coffee

Source: https://en.wikipedia.org/wiki/Malawi

Figure 2: Map of Malawi, in Eastern Africa.

2.2 Smart Irrigation and Flood Prevention

In the last 20 years, an extensive analysis has been carried out on the technical challenges of automated irrigation, together with multiple attempts at providing the design of the hardware and of the network infrastructure (Kim et al., 2009; Gutiérrez et al., 2013). The majority of these works make use of densely located wireless humidity and in-field water sensors connected to the internet.

Another related field is smart flood disaster prediction. It has been shown that using a sensor network monitoring humidity, temperature, pressure, rainfall, and water level it is possible to perform accurate flood prediction tasks (Bande et al., 2017).

In both these fields, the constraints described in the introduction and discussed in the rest of this work are not taken into account, and thus they are not easily transferable in the context of sub-Saharan Africa.

3 CONSTRAINTS

In this section, we discuss the main constraints that need to be considered when designing smart farming solutions in sub-Saharan Africa.

3.1 GSM Network & Mobile Hardware

Both the user application and sensor network interface should be implemented on top of the GSM network, because of the limitations on mobile hardware availability in sub-Saharan Africa. This in turns will introduce additional constraints: (i) low throughput, (ii) USSD/WAP protocol rather than modern Internet connection, (iii) need of a concise (often only textual or in any case in low resolution) representation of the processed data.

In practice, an USSD interface could allow a simple interface to: (i) the sensor network, (ii) the cloud application, (iii) the crowdsourcing interface. The users would not need a smartphone, nor will need to install any application to use the interface.

However, this would limit the complexity of the interaction with the sensor network and of the processed data, and would require significant design work to translate data, e.g. to visualise a trend or describe a map using only textual information.

3.2 Reliance on Electricity

The sensor network should be robust to lack of electricity, and thus be based on self-charging sensors equipped with a solar panel and a battery. This in turns will require the use of LoRA networks (Lavric et al., 2017; Wixted et al., 2016), with a constraints of the order of hundreds of mW per square centimetre. Moreover, the polling frequency of the sensor should be low, of the order of hours rather than minutes.

3.3 Low Cost of the Sensor Network

The need of limit the cost of the sensor network and the need of reducing the dependencies from external economic influences will require the need of using open hardware design and open network protocols, and the use of a limited number of sensors. For this reason, we believe that the nodes should be equipped with basic sensors like humidity, temperature, and pressure, leaving more complex measurement to crowd sourcing (e.g. for river water level) or via post-processing inference.

The need of an open protocol and the aforementioned constraints suggests that an ideal choice for the networking protocol would be OpenThread (Kim et al., 2019, Checco & Polese, 2020).

4 CONCLUSIONS

Building sustainability and scalability, often competing concepts, into ICT solutions has often been an issue in many Information and Communication Technologies for Development (ICT4D) projects in lower middle income countries (LMICs). The contexts of use of these ICTs tend to exhibit an uneven distribution of resources, with considerable regional variability. Thus, what may work in an urban centre may fail to provide the same results in a village or other rural community. ICT solutions in such environments tend to rely on contingent conditions and often the cause of failure is rooted in a lack of attention to contextual particularities (Davison & Martinsons, 2016). One group of ICT4D researchers in health innovations in LMICs have reported some success in addressing both the sustainability and scalability issue by adopting what they refer to as flexible standards (Braa et al., 2007). The concept is embedded in theory from science and technology studies, but nonetheless useful in acknowledging that sustainability and scalability need to consider ICT innovations as encompassing both people and technology acting within a particular context. Such solutions also embrace the notion of openness, thus encouraging collaborative endeavour and avoiding proprietary software/systems or platforms.

From a technical standpoint, we envision an infrastucture as depicted in Figure 3, where the use of low cost (mainly humidity, temperature, and pressure), long range and low-power sensors on top of an OpenThread infrastructure are connected to GSM supernodes able to provide a local USSD API

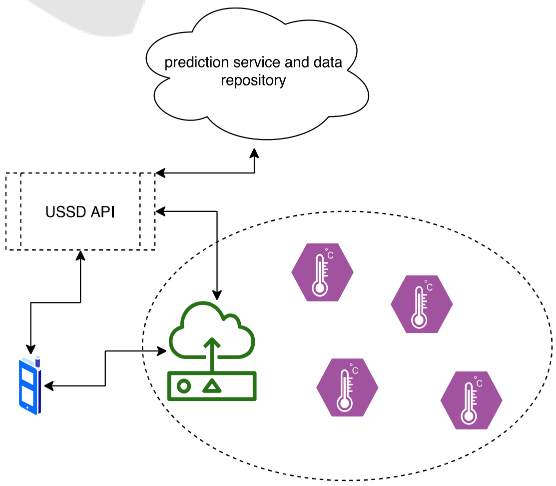

Figure 3: Low cost LoRa Infrastructure example.

and a cloud USSD user interface. Such API would also allow the collection of crowd sourced data, e.g. for river water level measurements.

REFERENCES

Adhikari, U., Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa: A review of impact on major crops. Food and Energy Security, 4(2), 110–132. https://doi.org/10.1002/fes3.61

Bande, S., & Shete, V. V. (2017, August). Smart flood disaster prediction system using IoT & neural networks. In 2017 International Conference On Smart Technologies For Smart Nation (SmartTechCon) (pp. 189-194). IEEE.

Beddington, J., Asaduzzaman, M., Clark, M., Fernández, A., Guillou, M., Jahn, M., Erda, M., Mamo, T., Van Bo, N., Nobre, C., Scholes, R., Sharma, R., & Wakhungu, J. (2012). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. (p. 64). CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org/commission

Braa, J., Hanseth, O., Heywood, A., Mohammed, W., & Shaw, V. (2007). Developing Health Information Systems in Developing Countries: The Flexible Standards Strategy. MIS Quarterly, 31(2), 381–402. https://doi.org/10.2307/25148796

Brisco, B., Brown, R. J., Hirose, T., McNairn, H., & Staenz, K. (1998). Precision agriculture and the role of remote sensing: a review. Canadian Journal of Remote Sensing, 24(3), 315-327.

Busingye, J. D. (2017). Smallholder farming and food sovereignty in Uganda: An in-depth analysis of policy vis-a-vis farmers' realities. Net Journal of Agricultural Science, 5(4), 131–140.

Checco, A., & Polese, D. (2020). Internet of trees: A vision for advanced monitoring of crops. In SENSORNETS 2020 - Proceedings of the 9th International Conference on Sensor Networks.

Davison, R. M., & Martinsons, M. G. (2016). Context is king! Considering particularism in research design and reporting. Journal of Information Technology, 31(3), 241–249. https://doi.org/10.1057/jit.2015.19

Ge, Y., Thomasson, J. A., & Sui, R. (2011). Remote sensing of soil properties in precision agriculture: A review. Frontiers of Earth Science, 5(3), 229-238.

Gutiérrez, J., Villa-Medina, J. F., Nieto-Garibay, A., & Porta-Gándara, M. Á. (2013). Automated irrigation system using a wireless sensor network and GPRS module. IEEE transactions on instrumentation and measurement, 63(1), 166-176.

IFAD. (2013). Smallholders, Food Security, and the Environment. International Fund for Agricultural Development. https://www.ifad.org/documents/38714170/39135645/smallholders_report.pdf/133e8903-0204-4e7d-a780-bca847933f2e

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jawad, H. M., Nordin, R., Gharghan, S. K., Jawad, A. M., & Ismail, M. (2017). Energy-efficient wireless sensor networks for precision agriculture: A review. Sensors, 17(8), 1781.

Kim, H. S., Kumar, S., & Culler, D. E. (2019). Thread/OpenThread: A compromise in low-power wireless multihop network architecture for the Internet of Things. IEEE Communications Magazine, 57(7), 55-61.

Kim, Y., Evans, R. G., & Iversen, W. M. (2009). Evaluation of closed-loop site-specific irrigation with wireless sensor network. Journal of irrigation and drainage engineering, 135(1), 25-31.

Lavric, A., & Popa, V. (2017, July). Internet of things and LoRa™ low-power wide-area networks: a survey. In 2017 International Symposium on Signals, Circuits and Systems (ISSCS) (pp. 1-5). IEEE.

Liaghat, S., & Balasundram, S. K. (2010). A review: The role of remote sensing in precision agriculture. American journal of agricultural and biological sciences, 5(1), 50-55.

Makoye, K. (2013, November 4). SMS weather advice cushions Tanzanian farmers from drought [Thompson Reuters Foundation News]. News.Trust.Org. https://news.trust.org/item/20131104120841-2fm9a/

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences of the United States of America, 104(50), 19680–19685. https://doi.org/10.1073/pnas.0701855104

Musoni, M. (2020, May 28). How to: Smart Farming in Rwanda with an IoT-based irrigation system. Digital Transformation Center Kigali. https://digicenter.rw/smart-farming-in-rwanda-with-an-iot-based-irrigation-system/

Nahayo, L., Habiyaremye, G., Kayiranga, A., Kalisa, E., Mupenzi, C., & Nsanzimana, D. F. (2018). Rainfall variability and its impact on rain-fed crop production in Rwanda. American Journal of Social Science Research, 4(1), 9-15.

Palmer, T., & Darabian, N. (2017). M'chikumbe 212: A mobile agriculture service by Airtel Malawi. GSMA. https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2017/07/M%E2%80%99chikumbe-212-A-mobile-agriculture-service-by-Airtel-Malawi.pdf

Perry-Castañeda Library Map Collection (2016). [online] Available at: https://legacy.lib.utexas.edu/maps/cia16/tanzania_sm_2016.gif [Accessed 17 December 2020].

Stewart, R., Erasmus, Y., Zaranyika, H., Silva, N. R. D., Muchiri, E., Korth, M., Langer, L., Madinga, N., Randall, N., & Wet, T. (2014). PROTOCOL: The Effects of Training, Innovation and New Technology on African Smallholder Farmers' Wealth and Food Security: A Systematic Review. Campbell Systematic Reviews, 10(1), 1–87. https://doi.org/10.1002/CL2.129

Tall, A., Hansen, J., Jay, A., Campbell, B., Kinyangi, J., Aggarwal, P. K., & Zougmoré, R. (2014). Scaling up climate services for farmers: Mission Possible (No. 13; p. 44). CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in Smart Farming – A review. Agricultural Systems, 153, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

Woodhouse, P., Veldwisch, G. J., Venot, J.-P., Brockington, D., Komakech, H., & Manjichi, . (2017). African farmer-led irrigation development: Re-framing agricultural policy and investment? The Journal of Peasant Studies, 44(1), 213–233. https://doi.org/10.1080/03066150.2016.1219719

Wixted, A. J., Kinnaird, P., Larijani, H., Tait, A., Ahmadinia, A., & Strachan, N. (2016, October). Evaluation of LoRa and LoRaWAN for wireless sensor networks. In 2016 IEEE SENSORS (pp. 1-3). IEEE.

Wouters, B., Barjis, J., Maponya, G., Maritz, J., & Mashiri, M. A. M. (2009). Supporting home based health care in South African rural communities using USSD technology. Association for Information Systems.