Adopting Digital Solutions for Large Scale Surveillance of Crop Pests and Diseases in Developing Countries—A Review

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Crop pests and diseases are ranked as some of the world's leading threats to agricultural productivity. The need to improve adoption of digital solutions prompted a review on the applicability of emerging digital solutions in large-scale surveillance of crop pest and diseases. This study presents findings on key requirements for achieving digitized large-scale pest surveillance, fitness for purpose of common autonomous biosecurity surveillance technologies, and prospects of smartphones as an alternative surveillance solution. Firstly, the research identified appropriateness of the solution, availability of supporting infrastructure and level of stakeholder involvement in solution formulation as some of the key determinants of digital solution adoption. Although most common autonomous biosecurity surveillance technologies are promising, their adoption in developing nations are limited by operational costs, legal requirements, skillsets, and operational environments among others. Thirdly, recent advancements in smartphones and wide spread ownership among farmers provide a unique opportunity for advancing Mobile Crowd-Sensing solutions in achieving large-scale pest surveillance. Lastly, we recommend designing an incentive mechanism to motivate farmers' participation in a surveillance solution.

Keywords: digital solutions, surveillance technologies, incentive mechanisms, large-scale surveillance, mobile crowd-sensing

INTRODUCTION

The current world growing population which is estimated to exceed 9 billion mark by 2050 has raised anxiety over the level of preparedness to curb the looming food security against the declining agricultural productivity (FAO 2017). Crop pests and diseases have been ranked as the leading threats to agriculture especially among smallholder farmers in developing countries (Nghiem et al. 2013). This threat has prompted the urgency to improve the surveillance of crop pests and diseases at regional, national and international levels (Pratt, Constantine & Murphy 2017). At the national levels, National Plant Protection Organizations (NPPOs) have been given the mandate to manage and coordinate pest surveillance system to ensure each country takes appropriate and prompt action on newly introduced pests. Surveillance enables NPPOs to define pest distributions and assist early detection of high priority quarantine pests before they have a significant impact on country's plant resources and its economy (Sappington et al. 2018). Through effective surveillance, crop pests and diseases can be detected, identified and managed early enough before causing severe damage to crops (Sappington et al. 2018). Because of this, surveillance is considered as the foundation that enables an NPPO to contribute to national food security, environmental protection and trade (IPPC 2016). Each country should therefore promote best practices in surveillance design, planning and implementation to ensure evidence-based reporting on pest status. Otherwise, inconsistent approaches to pest surveillance and poor standard of reporting of surveillance outcomes undermines the credibility of any claimed pest status.

Irrespective on the level of operation (whether regional, national or international) a good Surveillance framework should enable more cost-effective collection of pest records, more robust management of pest data, and more credible and timely reporting of changes in pest status (STDF 2021). In an attempt to increase crop productivity, several efforts have been made to automate agricultural activities in the last decade to reverse the current and future food crisis (Reddy 2018). According to Vanegas et al. (2018), automation trend is rapidly transforming traditional farming into smart farming where technological solutions are now used in irrigation, weed control, plant health monitoring, and pest and disease control among others. The recent advancements in Information and Communication Technologies (ICTs) have also presented an opportunity for the development of electronic surveillance (e-surveillance) systems aimed at assisting farmers in sharing biosecurity experiences with agricultural support systems (Kumar, Sarkar & Pradhan 2019; Singh & Gupta 2016).

Despite the growth witnessed in digital surveillance technologies, their efficacy depend on the type of surveillance being conducted, infrastructure, and technology characteristics such as spatial and temporal attributes, and applicability to specific biosecurity areas (Jurdak et al. 2015). Research indicates that farmers in developing countries continue to incur more losses from crop pest and diseases than their counterparts in developed countries despite the existence of innovative technologies meant to improve surveillance and control (Boratynska & Huseynov 2017; Zienkiewicz 2016). Ruzzante, Labarta and Bilton (2021) identifies the four determinant factors for technology adoption as externalities, entrepreneurial leadership, resources readiness, and absorptive capability. Resource readiness and absorptive capability factors which somehow correlate to poverty and illiteracy indexes respectively are potential contributors to the disparity between adoption of digital surveillance solutions by farmers in developing and those in developed countries. However, with the integration of Artificial Intelligence (AI) in sensor-based mobile devices, some of the adoption challenges with common biosecurity surveillance technologies could be addressed (Cui et al. 2018; Ullo & Sinha 2020). Therefore, in a bid to motivate the adoption of digital solutions in the surveillance and control of crop pest and disease in developing countries, there is need to; review surveillance landscape in developing nations, explore the extent to which the surveillance needs are met by available technologies, and recommend digital solutions that would stimulate large scale surveillance and control of pests.

Research Objectives

The slow adoption of pest surveillance technologies by farmers in developing nations has impacted negatively on crop pest and disease control efforts despite the potential of these digital solutions to improve detection, reporting and monitoring of biosecurity threats and incursions. The existing situation necessitated a review of the aptness and adaptability of emerging digital solutions in large-scale surveillance of crop pest and diseases in developing nations. In achieving the desired research objective, this research seek to answer the following questions:

i) What are the requirement of a digitized large scale crop pest and disease surveillance and control?

ii) What is the fitness for purpose of common autonomous biosecurity technologies in achieving large-scale surveillance in developing nations?
iii) What is the applicability of mobile crowd-sensing in achieving large-scale surveillance for pest and disease in developing nations?

Methods

The research was done through a systematic review and analysis of published literature on crop pest surveillance and associated surveillance technologies. Using keywords, search tools such as Google scholar, IEEE Xplore, Science Direct were used to identify credible and relevant literature for the research. Out of the many articles reviewed, a total of 94 articles were considered based on their relevance and impact of source journals.

REQUIREMENT FOR DIGITIZED LARGE SCALE CROP PEST AND DISEASE SURVEILLANCE AND CONTROL

The speed with which crop pests and diseases are spreading across regions has been increasing in the recent past due to climate change, globalization and trade (Zayan 2019). In an attempt to contain the spread, efforts have been made to improve on the surveillance and control through application of scalable ICT solutions. Since biosecurity threats can span wider regions within a shorter period of time, monitoring systems should be distributed across all the focus areas to capture any threat (Jurdak et al. 2015). The essential goal of crop pest and disease surveillance has been to facilitate early detection and monitoring for timely and appropriate control before getting to a stage that is too difficult to eradicate (Holden, Nyrop & Ellner 2016). Early detection of crop pests and diseases not only increases the success of eradication but also makes other rapid response measures possible and less costly (Epanchin-Niell & Liebhold 2015). Venter (2019) considered surveillance as a better option to calendar-based pest treatments since pests can be managed prior to firm establishment of a higher population. Surveillance provides field-specific information on pest and disease pressure and crop injury which is crucial in making decision on control methods (Keren et al. 2015; Vennila et al. 2016). As a solution to mapping strategy, PHA (2020) asserts that surveillance generally provide information on pest population levels and aid in the identification of high risk pathways and high-risk areas which can easily guide future surveillance efforts. Therefore, as a strategy to curb crops pests and diseases, deliberate effort should be made to augment current surveillance approaches.

Types of Surveillance

Pest and disease surveillance can be classified according to the purpose for which the surveillance is conducted, its primary focus and duration. According to ISPM (2018) surveillance can either be classified as general/passive or specific/targeted. While specific surveillance is aimed at obtaining information on target pest, disease or a host of concern within a given area over a defined period of time, passive surveillance focuses on the detection and diagnosis of all types of crop and diseases irrespective of their regulatory status (FAO 2020). Passive surveillance generally entails the process of continually gathering information on particular pests and diseases of concern from many sources and reporting to relevant organizations (FAO 2016). In addition to the occasional targeted surveillance, more attention should be given to general/passive surveillance for continuous monitoring crop pest and diseases that has always affected smallholder farmers' productivity in developing countries.

Surveillance Infrastructural Requirement

A country's capacity to conduct any type of crop pest and disease surveillance is defined by its existing infrastructure (ISPM 2018). Crop pest and disease surveillance infrastructural components entails monitoring, data collection, diagnosis, reporting and control (IPPC 2018). Traditionally, pest surveillance in developing countries has always relied on either personnel who spot pests during routine field surveys or samples brought to laboratories. However, according to Carvajal-Yepes et al. (2019), the first detectors of pest and disease outbreaks are usually networked groups of farmers, trained agronomists, service clinics supporting farmers, extension service personnel, private crop consultants, and pesticide salespeople and applicators. The effectiveness of any surveillance infrastructure is measured by the level of coordination between first detectors and downstream responders (Ochilo et al. 2018). According to IPPC (2018), the critical elements to be coordinated in a surveillance framework include; mechanisms to facilitate reporting, tools for collecting reports, systems or processes to enhance the quality of reporting, means to consolidate, analyse and communicate the information gathered. Failure to synchronize any of the elements in the framework is likely to create the weakest link in the surveillance chain.

Though general surveillance has the most in-field monitoring eyes, Pratt, Constantine and Murphy (2017) asserts that it is the least coordinated from local to global due to existing weaknesses in information sharing and inaccessible diagnostics solutions. Timely and effective intervention in the face of an emerging pest or disease situation requires that surveillance data be promptly shared within key stakeholders (support systems, researchers, farmers etc) for real-time corrective action (Singh & Gupta 2016). It is therefore necessary to improve on the existing crop pest and diseases surveillance infrastructure by seamlessly integrating and coordinating all its key elements.

Engagement of Farmers in Crop Pest and Disease Surveillance

The effectiveness of pest and disease surveillance is dependent on the active monitoring and transmission of pest and diseases data to relevant levels for mitigation strategies (GoK 2018). Improving current surveillance approaches require better methodologies of data collection, fast and cheap identification methods, epidemiological knowledge, and information on available controls (Toepfer et al. 2019). Poor management of pest data and sparsity of information in low income countries usually inhibits execution of preventive measures (Gosine 2016). The success of surveillance effort can be measured by the quality of surveillance data, the efficiency with which the information is transmitted and the effectiveness of the decisions and advisories arising from the surveillance system. Therefore, to support smallholders farmers, it is necessary to establish a surveillance system through which farmers can link with experts to share information and receive advise wherever they come across unfamiliar pests and diseases in their farms (PHA 2020). As in-field eyes, farmers can perform visual inspection, take photos of infected crops, record incidences and transmit to experts or expert systems for diagnosis and advisory. Involving farmers in supporting visual inspection and survey of crops underpins the major aspects of monitoring system for a large scale crop pest and diseases surveillance for the rural areas (Hatab et al. 2019).

Crop pests and diseases management require open interaction amongst agricultural stakeholders for enhanced monitoring and forecasting based on pest reports (Kumar, Sarkar & Pradhan 2019). According to Zienkiewicz (2016), the expanding telecommunication infrastructure is now opening more and flexible communication channels between farmers and agricultural support systems. However, the likelihood that farmers would report high priority pest incidences for necessary support is still uncertain (Wright et al. 2018). As one of the potential data sources in crop pest and diseases surveillance framework, it is important to examine and recommend how smallholder farmers can effectively be involved the surveillance matrix.

Use of ICTs in Crop Pest and Disease Surveillance

ICT applications can make a significant contribution to meet future global food need by collecting and sharing timely and accurate agricultural information (Awuor et al. 2016). The strategic application of ICT in information sharing has significantly improved the economic welfare of developing countries (Baumüller 2017). ICTs have improved farmers accessibility to agricultural information as well as opportunity to dialogue amongst themselves and with agricultural experts (Eitzinger et al. 2019). Wilkinson, M et al. (2016) argues that incorporating ICTs in biosecurity surveillance can potentially incentivize data sharing by deploying FAIR (findable, accessible, interoperable, and reusable) data principles. Even though individual regions might restrict sharing of sensitive agricultural information (Ribeiro, Koopmans & Haringhuizen 2018), an effective ICT-based crop pest and disease surveillance system should be established on FAIR data principle.

According to Carvajal-Yepes et al. (2019), a functional surveillance network should ensure timely and secure transfer of pests and diseases knowledge between predetermined sources and approved recipients. As observed by Isard et al. (2015), the culture of exchanging crop pest and disease information between the agricultural community is likely to benefit everyone who is directly or indirectly involved in pest and diseases management from Agri-tech solution providers, Agricultural research institutions, agronomist and farmers amongst other interested stakeholders. Therefore, it is necessary to establish how the full potential of ICTs in information capture, storage, processing and sharing can be realized in the surveillance of crop pest and diseases.

Digital Identification and Diagnosis of Crop Pests and Diseases

As the ratio of smallholder farmers to agricultural extensions officers continue to increase, accessibility to expert advice is significantly diminishing thereby exposing majority of the farmers to the risk of applying erroneous controls (Selvaraj et al. 2019). Pest identification and diagnosis is such a technical area that even at times experts can occasionally make wrong judgments. For example, a study conducted in Australia to establish the ability of agronomists to correctly identify and recognise the top four pests that pose the greatest threat to grain farmers was way below expectations (Wright et al. 2016). In response to these challenges, various diagnostic technologies have been emerging and transforming pest and disease management across the globe (Nielson et al. 2018). The demand for automating crop pest and disease management has therefore attracted research attention in computer vision techniques, machine learning and automated insect pest recognition (Wu et al. 2019). These novel technologies can potentially reduce human error in diagnosis and identification of crop diseases and pest respectively (Pradeep et al. 2019).

The developments in Artificial Intelligence (AI) has made it possible to simulate human intelligence in ICT systems which can now perform tasks like visual perception, and decision-making (Selvaraj et al. 2019). Some of the specialist apps can now help farmers identify pests, as well as record their spread and location through the phone's IP address and geo-point values. Currently in smart agriculture, Astonkar and Shandilya (2018) asserts that images for the crop can now be uploaded into diagnostics systems where they undergo several processing steps to detect the severity of infection based on the comparison with the trained dataset images. For example, the uploaded images can now be resized and their features extracted on parameters such as morphology, Colour Coherence Vector (CCV) before using k-means clustering algorithm to classify them as either infected or non-infected (An et al. 2008; Selvaraj et al. 2019). As accessibility to agricultural expertise continue to reduce against the rising demand for crop pest and diseases expertise, embracing automated control solutions holds the key to the future of subsistence agriculture in developing countries.

FITNESS FOR PURPOSE OF AUTONOMOUS BIOSECURITY SURVEILLANCE TECHNOLOGIES IN DEVELOPING NATIONS

The application of technology-based non-contact methods for detecting and monitoring crop pests and diseases has revolutionized crop protection (Preti, Verheggen & Angeli 2021). Based on their characteristics, different remote sensing methods have been used in the surveillance of crop pests and diseases (Zhang, J et al. 2019). Some of the autonomous biosecurity surveillance technologies commonly used in pest and disease surveillance include; Wireless sensor networks, Ground robots, and Unmanned Aerial Vehicles. This paper presents a review of surveillance technologies and further examines their limitations and available alternatives with reference to technologies, requirements and application environment.

Ground Robots

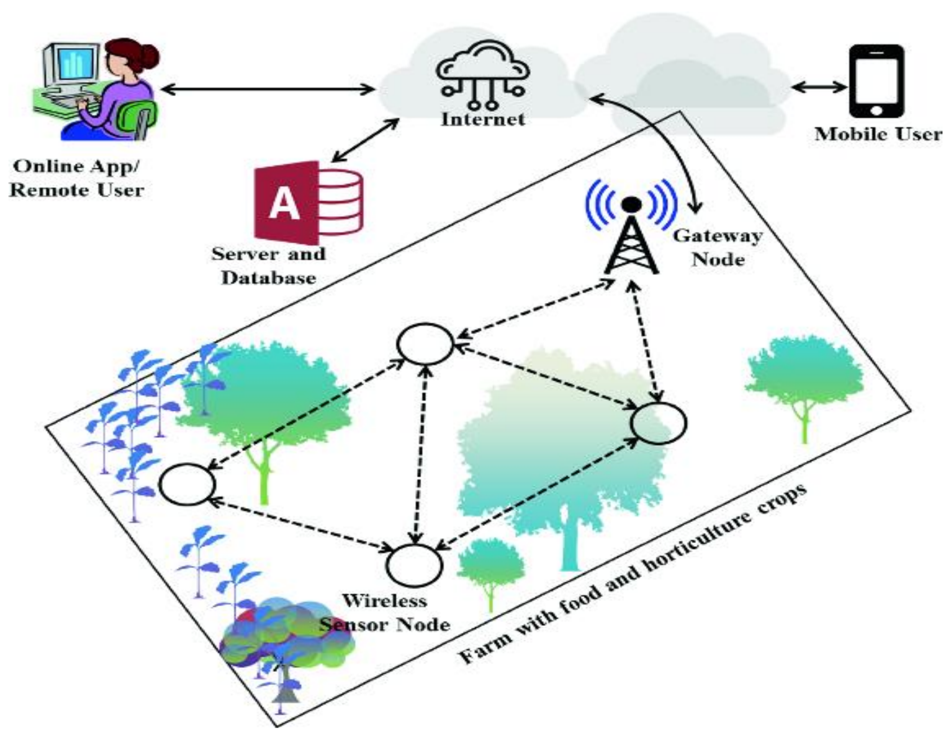
Ground robots also referred to as terrestrial robots have some form of mobility and can traverse the environments at predetermined times and locations to acquire data at high spatiotemporal resolution at a user's request or autonomously (Jurdak et al. 2015). With higher processing capability and a higher-quality sensor payload, ground robots can provide quantitative and qualitative analysis of the data (Zhang, Y et al.

2012). They can interrogate different areas of the farm in greater detail and conduct on board processing and reasoning, thereby providing analytical results. With their potential to support crop pest and disease surveillance, ground robots must operate in unstructured environments without impairing the quality of work to be achieved (Pant et al. 2019). However, safe navigation of ground robots has been one of the hardest development challenge for the last decade since their introduction in agricultural activities (Santos, Santos & Valente 2020). The challenge revolves around localisation, mapping, motion control, and path planning which are essential in navigation within the intricate, unstructured, and fickle agrarian fields (Mac et al. 2016). With the high level of illiteracy and poverty among most smallholders in developing countries, acquisition and adoption of ground robots in pest and crop surveillance in rural farms may wait a little longer due to the financial, operational and technical constraints that currently limit their applicability in most of the third world countries.

Wireless Sensor Networks

Wireless sensor networks (WSNs) consists of spatially distributed autonomous sensors to monitor the physical environment and forward the collected data to a central location (López et al. 2012). WSN has been instrumental in measuring environmental conditions such as humidity, temperature, wind, sound and pollution levels (Srivastava et al. 2013). Their use in biosecurity management is one of the latest ICT intervention in agriculture (Panda 2020). WSN can now support monitoring of different crop parameters, pest indications, related disease and crop concurrent status (Azfar, Nadeem & Basit 2015). With the integration of Internet of things (IoT) devices in WSNs (Figure 1), it is now possible to use AI based monitoring and control methods in plant health monitoring (Ullo & Sinha 2020).

FIGURE 1
WIRELESS SENSOR NETWORKS FOR PRECISION AGRICULTURE (DASIG, 2020)



Though WSNs have gained a lot of popularity in the developed countries for improving agriculture output, they suffer serious limitations in memory, computing, battery life, and bandwidth (Patil & Chen 2017). The adoption of WSN technology as surveillance technique has equally been very slow in developing countries due to factors such as cost and unawareness of the technology (Azfar et al. 2018).

Even with the high temporal frequency observation which allows WSN to operate independently for a long period of time, they have limited spatial resolution and small spatial coverage because of the infrastructure deployment and maintenance cost constraints (Gupta, Kumar & Jain 2016). It has always been expensive to build NSW and hence cannot be affordable by all especially smallholder farmers in developing countries.

Unmanned Aerial Vehicles - Drones

Unmanned aerial vehicles (UAVs) are unpiloted flying robots encompassing drones, micro-, and nano aerial vehicles. Though initially developed for military surveillance, UAVs are now used in agricultural activities including, crop heath monitoring, pest control, and crop irrigation among others (Ayamga, Akaba & Nyaaba 2021). UAVs are integrated with advanced digital multispectral, hyperspectral, and RGB sensors which provides reliable data collection protocols and methods to achieve faster processing techniques while integrating multiple sources of data in diverse remote sensing applications (Vanegas et al. 2018). The advances in remote sensing imagery and geospatial image processing has enhanced the application of UAVs in crop monitoring and protection (Maslekar, Kulkarni & Chakravarthy 2020). UAVs can now generate better and more detailed images than satellite maps or helicopter-based thermography (Christensen et al. 2021). By scanning crops using both visible and near-infrared light, UAV can detect temporal and spatial reflectance variations and associate it to crop health. The integration of machine learning techniques in UAV is now a promising technology to achieve pest and diseases surveillance (Maslekar, Kulkarni & Chakravarthy 2020).

The UAVs' performance is generally based on their average weights, payload size and flight time with the major types being Multi-rotor, Fixed-wing, Single-rotor Helicopter and Fixed-wing-multi-rotor Hybrid (Yinka-Banjo & Ajayi 2019). Although they have been used in agriculture for over two decades, UAVs still suffer from their costs, technical limitations, safety and legal related issues (Hayden 2021). Morley et al. (2017) identifies payload capacity, battery limitations, weather, flight-time restrictions and civil aviation authority (CAA) regulations as major bottlenecks to UAVs' applications in agriculture. While most basic drones have less flight time and covers less area, their advanced counterparts with higher payload, long range and long flight time are costlier to acquire and maintain. The application of drones in agriculture requires regulatory framework to address associated operational safety, privacy and national security concerns (CTA 2019). However, the use of UAVs for agricultural purposes is yet to be approved by many underdeveloped and developing countries' national aviation authorities for use in the skies (Hayden 2021). Hence, the application of UAVs in pest and disease surveillance in Africa may stagnate until policies, laws and regulations governing their use are put in place. According to FAO and ITU (2018), only fifteen countries in Africa had put in place the regulations governing the use of UAV by 2017, seven other countries had minor reference to their existing aviation regulations and three countries were underway in enacting the required legislations (Table 1).

TABLE 1
STATUS OF UAV REGULATIONS IN AFRICA

Status	Countries
Regulations are in place	Cameroon, Botswana, Gabon, Rwanda Ghana, Madagascar, Mauritius, Nigeria Namibia, Seychelles, Swaziland, South Africa, Tanzania, Zimbabwe and Zambia
Minor references in aviation regulations	Benin, Mali, Chad, Côte d'Ivoire, Burkina Faso, Senegal and Mauritania.
Pending Regulations or being developed	Angola, Malawi and Kenya

(Sources: FAO and ITU (2018)

Though UAV presents itself as an effective pest and diseases surveillance technology for developing countries, its operational, technical and financial requirements may need the support of several development agencies and international research institutions but the current legal void has frustrated such attempts (FAO & ITU 2018). It is therefore evident that technological limitation and legal framework may impede some of the ICT based surveillance solutions. When policy or regulation does not support the use of a technology, then the implementation of such technology cannot take place within the affected jurisdiction even though the technology may be beneficial to the society. In such instances, an alternative solutions has to be explored.

Limitations of Common Biosecurity Surveillance Technologies

Since biosecurity threat is expansive, the first challenge of autonomous systems is around spatial scale and resolution which requires that detection technologies be distributed over large areas and provide sufficient spatial resolution. Secondly, duration and temporal resolution of some the technologies has been a concern since the much needed continuous monitoring of vulnerable crops may not be achieved due to limited energy supply to power these systems in the fields. The third concern for autonomous surveillance technologies has been guaranteeing fitness of purpose. Biosecurity threats are often multidimensional (Velusamy et al. 2012; Wilkinson, K et al. 2011), with diverse monitoring and management requirements depending on context. The temporal and spatial scale at which a threat propagates in the landscape varies from one place to another (Meloni et al. 2011) which makes the choice of corresponding technology much difficult. This diversity of how quickly biosecurity problems spread requires matching technology solutions (Trad, Jurdak & Rana 2015). Table 2 below summaries some of the characteristics of the three common surveillance technologies and their applicability in a given context.

TABLE 2
CHARACTERISTICS OF SURVEILLANCE TECHNOLOGIES AND APPLICABILITY TO SPECIFIC BIOSECURITY AREAS

Technology	Duration	Spatial resolution	Spatial coverage	Adaptivity	Temporal resolution	Utility	Biosecurity application area
Fixed sensors	Long	Low	Low	Temporal	High	Continuous monitoring/ communications relays	Vector-borne disease, plant pests
Ground robots	Short	High	Low	Temporal and spatial	High	Terrestrial surveys	Plant pests and diseases
UAVs	Variable	High	High	Temporal and spatial	High	Aerial surveys	Plant pests and diseases

Source: Jurdak et al. (2015).

APPLICABILITY OF SMARTPHONES IN LARGE-SCALE SURVEILLANCE AND CONTROL OF CROP PESTS IN DEVELOPING NATIONS.

With the limitations of existing autonomous surveillance technologies, smartphones presents an alternative solution to pest and diseases surveillance in developing countries. The advancements in semiconductor technology has seen the integration of a number of physical sensors (for example, positioning sensors, gyroscope, motion sensors, accelerometer, high resolution cameras among others) in smartphones (Chessa et al. 2016; Huang, Kanhere & Hu 2014). The growth and diversity of sensors on smartphones combined with their mobility provide a unique opportunity to harvest large-scale sensing surveillance data with fine-grained spatio-temporal coverage (Guo et al. 2015). The use of mobile smartphones in sensing applications has given rise to numerous sensing applications due to other prominent advantages such as good scalability, low cost and ubiquitous application scenarios (Xu, Xiang & Yang 2015). The smartphones powered by novel sensing technologies, artificial intelligence (AI) and machine learning (ML) algorithms create a new intelligent intermediary layer between people and systems to solve complex problems (Mendes et al. 2020). AI-based mobile phone applications have the potential to provide small-scale farmers and extension agents an effective, low-cost and easy-to-use pest and disease diagnostic solution (Chepkwony, Bommel & Langevelde 2020; CIP 2020)

Recent developments in smartphone technologies has also resulted into high processor, bigger memory, and bigger storage making it possible for them to run complex applications in different domains such as, agricultural systems, health monitoring system, environmental monitoring, traffic monitoring and etc (Mafrur, Nugraha & Choi 2015). Some of the identified constraints that limit the use common autonomous biosecurity surveillance amongst rural farmers can now be addressed by smartphones sensing applications. Sensor-based smartphones have become promising tools in biosecurity surveillance because of their mobility, accessibility, and computing power that allows them to run a variety of practical applications (Zhang, J et al. 2019). The smartphones gain their mobility in sensing tasks from human involvement which offers unprecedented opportunities for both sensing coverage and data transmission (Ma, Zhao & Yuan 2014).

In addition to the above prospects in surveillance, mobile technology has given rise to development of mobile applications for agricultural consultants and farmers with support tools and educational materials (Ciampitti & Albers 2016). Most of the pest management apps "Ag-Apps” can now assist in crop pest identification, disease diagnosis, nutrient analysis, and suggest control solutions among other functionalities. The adoption of these mobile-based “Ag-Apps” can potentially bridge the gap between “Information-haves” and “information-have-nots” thereby reducing the “digital divide.” (Panda 2018).

Opportunity for Smartphone Application in Crop Pests and Disease Surveillance

The ownership and use of smartphones in recent years have experienced rapid growth. Statista (2021) estimates the number of smartphone users in the world today at 6.378 billion and project it to be 7.49 billion by 2025 which translates to 80.63% of the world’s population owning a smartphone. Locally, Statista estimates the number of smartphone users in Kenya at 21.69 million and estimate the number to rise to 33.45 million in 2025. ICTs continue to improve information exchange, collaboration, and knowledge diffusion (Perez et al. 2017). According to the World Economic Forum 2016, of 139 nations, for example, Kenya was ranked 86 on the Networked Readiness Index (NRI). This index measures a country’s propensity to benefit from the use of ICTs. It was reported that as of 2016, 73.8 out of 100 Kenyans had mobile phones. The current trends indicate a rise in the number of mobile phones and internet accessibility. According to Kenya Communication Authority(CA)’s, 2017 statistics report, the mobile subscription and penetration stood at 40.0 million and 90.4 per cent respectively (CA 2017). The CA report further indicate that 70% of the rural Kenya is currently covered by 3G network and the smartphones are increasing at a rate of more than 30% per year in the rural market.

The development and advancements of social media (for instance WhatsApp, Facebook, and Instagram, Twitter) has made it easy to create online communities through which farmers can share agricultural information (Vries 2016). The adoption of online community support service model can potentially strengthen the linkage between smallholder farmers and existing support systems (Zhang, Y, Wang & Duan 2016). According to Ngunjiri (2018), Kenya is current leading globally with 83 per cent in share of internet traffic coming from mobile phones. The state of network coverage and mobile phone penetration in Kenya is an indicator on the opportunity for smartphone technology application in crop pest and disease surveillance within the country.

Advancing Mobile Crowd - Sensing Paradigm in Pest Surveillance

Though the application of Mobile Crowd-Sensing (MCS) paradigm has been used majorly in environmental pollution and traffic monitoring, its application in agriculture especially in pest surveillance is still under explored. However, the adoption of MCS has the potential to radically transform crop pest and disease surveillance through the power of Artificial intelligence (AI), advanced sensor technology and citizen science (Mrisho et al. 2020). The advanced functionalities of mobile devices have created a new interface between human beings and environments (Zhang, X et al. 2016) and many mobile crowd-sensing applications have thus been designed to enable mobile device users contribute their resources (device power, communication, time, and effort costs) for sensing tasks. These sensors are able to record various information about the participants (e.g., mobilities and locations) and the environment (e.g.,images and sounds).

Since mobile crowd-sensing applications requires large amounts of participants (e.g., normal smartphone users) to sense the surrounding environment via the rich built-in sensors (Zhang, X et al. 2016), it needs sufficient participants. However, the users who participate in a sensor data collection task consume multiple resources of the smartphone, including computation, communication, and energy. MCS systems often face the challenge of insufficient participation due to the nontrivial costs to participants in terms of battery consumption, mobile data usage, time, effort and the need for long-term commitment in sensor-data collection even though there may be no direct benefit to the participants (Luo et al. 2017). As a result, many people would be reluctant to participate and share their sensing capabilities unless there is sufficient incentives to offset their sensing costs and risks. The likelihood of participants dropping out of the collecting loop is always high unless return on investment is greater than their expectations (Wei & Anwar 2017). Therefore the motivation of mobile device users to share sensing data is critical when the devices have very limited resources (e.g., energy and storage capacity) or the information revealed is highly sensitive (Wei & Anwar 2017).

In an effort to improve participation in sensing tasks, there has been growing attention within the research community on how to effectively and efficiently motivate users. Various scholars have proposed different approaches to solving the problem of motivation though various incentive designs for specific sensing tasks. In this era of technological advancement, the big research question that need to be addressed is, how can farmers can be motivated to participate in the pest sensing loop using their mobile sensors to achieve large-scale pest surveillance?

CONCLUSION AND RECOMMENDATIONS

The successful adoption of digital solutions for large scale surveillance of crop pests and diseases depends on the appropriateness of the digital solution and supporting infrastructure (people, technology and procedures) as key requirements. The findings underscore the need to seamlessly integrate the technology and stakeholders especially farmers in order to succeed in adopting digital solutions for crop pest and disease surveillance in developing nations. As potential data sources in surveillance framework, farmers should form part of any technology enabled surveillance matrix. Further findings reveal that most farmers and even some agricultural experts are unable to correctly identify and diagnose crop pest and diseases, hence the need for Artificial Intelligence (AI) based technologies which can potentially reduce human error in diagnosis and identification of crop diseases and pest. The application of technology-based non-contact methods (such as Ground Robots, WSN, and UAV) for detecting and monitoring crop pests and diseases has revolutionized crop protection across the globe. However, the findings indicate that their application in developing nations is facing challenges ranging from technology constraints, lack of regulatory framework, resource requirements, absorptive capability, and digital divide. Unless these challenges are addressed of which the timeframe may not be guaranteed with the current social-economic-political landscape in developing nations, adoption of these common technologies remains a mirage. Hence the need to refocus on alternative digital solutions to address surveillance requirements of developing nations.

The growth and diversity of sensors on smartphones combined with their mobility provide a unique opportunity for data sensing through Mobile Crowd-Sensing (MCS) paradigm. In addition, the smartphones powered by AI and machine learning (ML) algorithms has also created new intelligent intermediary layer between people and systems to solve complex surveillance problems which would otherwise require human expertise. Even though the research identified various application of MCS in environmental pollution and traffic monitoring, its application in agriculture is under explored but promising. The success of MCS applications requires large amounts of participants to sense the surrounding environment via the rich built-in sensors. However, the users who participate in a sensor data collection consume multiple resources of their smartphones and many of them become reluctant to participate and share their sensing capabilities unless there is sufficient incentives to offset their sensing costs and risks. In addressing the current problem facing surveillance and control of crop pests and diseases in developing nations, the research recommends the adoption of MCS based surveillance applications as an alternative solution. Based on this research findings and recommendation, further research should be advanced on the design and development of appropriate incentive mechanism to motivate farmers' participation in the crop pest and disease sensing task using their smartphones.

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