The Internet of Things in Agriculture for Sustainable Rural Development

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Abstract— Rural areas in South Africa and Zambia face a number of similar issues in the domains of agriculture, connectivity, water, transport, health and education etc., which calls for potentially similar solutions to be directed towards solving these issues. The intention of this research is to investigate the potential contributions of internet of things technologies (IoT) towards poverty reduction in these rural areas, in line with the needs identified in these communities and with emphasis on agriculture. The paper identifies examples of IoTs to mitigate the agricultural needs of these communities for the domains of crop farming, weather forecasting, wildlife management, forestry, livestock farming, market identification and rural financing.

Keywords—agriculture, rural development, internet of things

I. INTRODUCTION

Agricultural informatics, also referred to as e-agriculture, is a field which combines the advances in agricultural information, agricultural development and entrepreneurship to provide agricultural-services-enhanced-technology, dissemination and information delivery through information and communications technologies (ICTs) and the internet [9]. E-agriculture focuses on enhancing agricultural and rural development through improved information and communication processes. More specifically e-agriculture involves the conceptualisation, design, development, evaluation and application of innovative ways to use ICTs in the rural domain with a focus on agriculture [11]. ICT is an umbrella term that includes anything from radio to satellite technology to mobile phones or electronic money transfers. There is growing interest in the potential of internet of things technologies (IoT) to support poverty alleviation and the upliftment of the living standards of people in rural areas. The contribution of this research is the investigation of the potential contributions of IoTs to the domain of agriculture for rural environments of Zambia and South Africa. IoT on the other hand is the connecting of physical things to the internet which makes it possible to access remote sensor data and control the physical world from a distance [13]. The IoT has the purpose of providing an ICT-infrastructure facilitating the exchange of 'things' in a secure and reliable manner, i.e., its function is to overcome the gap between objects in the physical world and their representation in information systems [23].

The increase in ICT affordability, accessibility and adaptability has resulted in their use even within rural homesteads relying on agriculture. The drivers of ICT in agriculture are: 1) low-cost and pervasive connectivity, 2) adaptable and more affordable tools, 3) advances in data storage and exchange, 4) innovative business models and partnerships, 5) demand for agricultural information services [26]. Any ICT intervention that improves the livelihoods of poor rural farmers will have significant direct and indirect impacts on enhancing agricultural production, marketing and post-harvest activities, which in turn can contribute to poverty reduction [18].

For all rural areas, the barriers that need to be addressed by broadband ICTs are: 1) distance barriers, i.e., access to administrative and government services and structures, 2) economic barriers, i.e., access to wider business and labour markets, 3) social barriers of rural inhabitants' access to information, education and training, health, social services, etc., 4) traceability of production, products and services throughout the value chain including logistics[27].

The rest of the paper is structured as follows: Section 2 is the problem statement. Section 3 is on the state of

978-1-4799-7707-9/15/$31.00 ©2015 IEEE

agriculture in both Zambia and South Africa. Section 4 is on the potential IoT systems for agriculture. Section 5 is on related literature. Section 6 is on potential benefits of IoT to agriculture. Section 7 is the conclusion.

II. Problem Statement

Rural areas in South Africa and Zambia face a number of similar issues in the domains of agriculture, tourism, environmental management, finance, communications infrastructure, connectivity, water resources management, sanitation, roads and transport, access to markets, health and education, which calls for similar but locally relevant solutions to be directed towards solving issues related to these similarities. In order to respond to the needs of the rural communities, alleviate poverty and narrow the digital divide between urban and rural areas, this research recommends the adoption of information and communication technologies (ICTs), namely internet of things technologies (IoT), in the delivery of services to rural communities of both South Africa and Zambia. The intention of this research is to identify needs and recommend IoTs in response to these needs that will contribute to lessening the impact of poverty in the rural areas of both South Africa and Zambia, with emphasis on the agricultural sector.

The questions asked are:

- What are the agricultural needs of the rural communities that, when addressed, will lead to the upliftment of their lives and poverty alleviation
- What IoT technologies are in existence and what IoTs can in the future be designed and developed to meet these needs

The research objectives therefore will be:

- Review existing literature on the agricultural challenges in Zambia and South Africa
- Identify the IoT technologies that can address these needs through use cases

In order to effectively address the research problem, an interpretive approach is used [7]. The interpretive approach is based on qualitative methods to obtain and analyse data. It is critical in enhancing the researcher's understanding of human behaviour and action as it relates to the phenomenon under investigation. It is based on the notion that knowledge of reality can be best obtained through social construction which includes documents, shared meanings, etc. [5]. A literature review was conducted on both the agricultural needs/challenges of the rural communities, and IoT technologies that can be adopted to meet the needs/challenges. The final product is recommendations on IoT technologies for the domain of agriculture, looking specifically at solutions to the identified needs.

III. The Stae of Agriculture in South Africa and Zambia

According to Global Insight's 2009 estimates, 15.9 million South Africans live in poverty; and of these, 11 million people, representing 69% of all South Africans that live in poverty, live in rural areas. Poor households in rural areas depend on a combination of subsistence agriculture, social grants and remittances from family members working in cities or mines [22]. On the other hand, 90% of Zambia's rural residents are considered 'smallholder households' and derive most of their income from agriculture [15]. IoTs would enable access to agricultural services, identification and access to markets for produce; management of rural transport for farmers, communication with extension services for information on agricultural practice and for information of weather forecasts to mitigate agricultural risks.

The increase in agricultural production in Zambia during the 2009/2010 agricultural season compared to the 2008/2009 season shows the following: sunflower increased by 118%, soya beans by 50%, rice by 9%, maize by 38% and tobacco by 7% and wheat by 5% [17]. The South African agricultural sector is diverse including crop husbandry, horticulture, animal production, poultry production, forestry , dairy farming, fish farming, game farming and agro-processing are undertaken. According to Cousins (2009), agriculture employs 4.75 million South Africans of which 4 million are engaged in agriculture for 'own consumption' purposes [6]. IoT can be adopted in the management of agriculture, keeping track of animals in communal grazing lands, managing agro-processing factories, controlling irrigation systems and transport logistics management.

Over 90% of smallholder crop production in both Zambia and South Africa is rain-fed, so rainfall is a critical factor for selecting crops, their planting time, the timing and intensity of input and labour use and subsequent yields [4, 21]. IoT can be adopted for weather forecasting due to the unreliability of weather patterns and to mitigate agricultural risks.

In Zambia, the fisheries sector, because of its mostly rural setting, continues to contribute significantly to rural development in terms of employment and income generation and reducing poverty [17]. This creates immense opportunities in cold storage and haulage of fresh fish using refrigerated trucks and related logistics using IoT. South Africa has over 4700 storage dams about 700 of which are owned and controlled by the government. As a result South Africa is encouraging rural aquaculture for food security in public dams [19] IoT can be adopted in the management of aquaculture ventures.

83%, 97% and 68% of Zambian national cattle, goats and sheep respectively are found in smallholder farming systems or the traditional sector [17]. In South African livestock the estimated contribution of communal areas to pigs, poultry and ostrich is 26.5%, 32.6% and 0% respectively [6]. IoT can be adopted to keep track of livestock especially in rural areas

where there is communal grazing and animals are likely to get lost.

IV. Potential IoT Systems in Agriculture

The following sections give a few examples of potential applications of IoT in agriculture. For agricultural purposes and in an environment where the advent of climate change results in unpredictable rainfall patterns, automated drip irrigation can be adopted. Drip irrigation is the crop watering technique that waters only the soil closest to the plant's roots. Linking data on temperature, radiation, humidity and soil water content collected by various sensors, controls not only where water is released but how much is needed. Since the rural areas are endowed with renewable energy and there is little or no access to the electricity grid, these renewable energy technologies such as solar and wind can feed energy into water pumps which in turn pump water from underground into tanks. This water is used to irrigate crops.

Weather forecasting can be done through analysis of weather data over long periods to reduce agricultural risk. This is referred to as big data analysis. In weather forecasts for pest management, humidity, precipitation, crop type, soil fertility, leaf wetness, temperature, winds and soil moisture are collected at local level through sensors. The life cycle of pests is monitored along with the climate data, allowing researchers to predict pest outbreaks more accurately because pest maturation depends on environmental conditions.

To prevent stock theft, animals are fitted with radio frequency identifiers (RFIDs) that enable tracking of the animal. The position of the animal can be visualised on a map in a control centre through data remitted wirelessly. In rural areas where there is communal grazing, animals tend to get lost. Livestock are fitted with radio-frequency identifiers (RFID) chips and RFID readers are placed at various monitoring spots to transmit information to an agricultural extension services centre. The position of the animal can be queried.

The IoT can also enable branchless banking services. Farmers can deposit, withdraw and transfer money, and pay bills from a network of agents that include retail outlets, to the benefit of rural communities, who have no access to banks within a reasonable distance. A regional price information system could collect data from the main national markets and filter it out to local level through small information centres that have internet access. In more isolated communities, two-way or rural radio can be used to broadcast market prices to wider audiences.

Satellite light radiation can detect water pollution in the massive bodies of water. It uses the wavelength of pollutants to identify the class of pollutant. This technology would become handy in aquaculture. Flooding is a problem in river basins. A web site can be set up with real time presentation of a river basin. The ability to see what is happening throughout a river basin and react promptly to changing hydraulic and weather patterns can save a lot of lives in agricultural communities. Sensors monitor the environment in the river basin and wirelessly feed information into the website.

Veld fires are also a problem in rural areas. Satellite technology can be used to detect the fires through heat intensity sensors and photos which are transmitted wirelessly to the relevant stations. Trees can have plastic barcodes hammered into them, to prevent illegal logging of the coveted hardwoods. The tag on the tree is scanned as soon as the tree is cut, uploading the information via satellite to a secure database. The database tracks tree inventory, and provides reports. Trees can be tracked from the forest all the way through the supply chain to the consumer.

Organic greenhouses use technologies such as sensors to monitor and control temperature, humidity, soil aeration, soil moisture and drainage, fertility levels and light. The linking of these technologies with systems to control them can lead to smart systems that not only help farmers effectively utilize their resources but also lead to diversification where a wide range of crops can be grown. These organic greenhouses also require electrical energy to operate as expected. The form of energy will come from solar and wind energy, thus a system that integrates solar panels and wind turbines to sensors.

The IoT technologies can support precision agriculture, a form of agriculture whose goal is to maximize return on investment in agriculture. Irrigation / water detection / soil detection sensors give alerst to help protect a farmer's crop and relay information wirelessly to water reserve points on when to irrigate. Furthermore, farmers can adopt automated drip irrigation in areas where water is scarce. This can be achieved by linking data from various sensors which controls not only where water is released but how much is needed.

In order to minimize crop damage by plant eating pests, animals and veld fires among others, better in-field monitoring is required. This can be accomplished by building sensors that monitor the fields. These will be able to inform farmers of any attack on their crops or fires detected before they spread..

Various decision support systems that run on smart phones assist farmers plan for the following farming season. In addition, these applications help farmers diagnose crop and livestock diseases and prescribe medications to the identified diseases. Alternatively, in cases where a farmer visits several veterinary officers, villagers can carry smart health cards. These cards can store all their animals' information and is updated at every visit to the veterinary officer. For telemedicine to rural farmers, smart phones can be used to photograph and transmit images of affected livestock or crops to experts who prescribe remedies to the problems identified.

Public agriculture surveillance programmes enable decision makers guide agricultural interventions such as preventing the spread of plant eating pests or other plant diseases. Systems

that use IoT technologies, track and monitor farm animals and detect potential signs of diseases. These technologies can be integrated with a central system and help disseminate relevant advice to farmers. This can be used to identify outbreaks and trends. In addition, since livestock can be stolen, a system that monitors them using GPS technology can be put in place to detect their movement and alert the owners in case there are no detected animal movements for a certain period.

In order to facilitate the delivery of farm products to their destination, sensors that use IoT technologies such as GPS and RFID track and monitor farm products during transportation and storage. Since rural communities are sparsely populated, finding suitable transport to deliver products to their intended destination is a challenge. IoT systems can track farmers requiring transport to carry their farm products to intended destinations.

Satellite transmission can be made available in deep rural areas. This can connect to other areas via mesh technology. With this connectivity, rural farmers can have access to information on markets for their products and prices, government services and their rights.

To facilitate the purchasing of farm inputs and selling of farm products, buyers' and sellers' smartphones are equipped with IoT technologies such as Near-Field Communications (NFC) that facilitates the purchasing of products without using cash. Electronic transactions that debit or credit bank accounts for buyers and sellers instead replace exchange of cash. Such technologies also enable branchless banking services which is beneficial to rural farmers who have no access to banks within a reasonable distance. Mobile internet and low-cost sensors could enable farmers to interact directly with the consumers, cutting off the middleman. Kenya has developed M-Pesa kiosks in the rural communities for mobile money transfer. Farmers visit these kiosks for transactions with proceeds from sales within the community to pay for labour and inputs. Therefore money circulates within the agricultural community [10].

V. RELATED LITERATURE

Although developed countries have led the world in ICT use for over two decades, the past decade has seen unprecedented growth in ICT usage by developing countries. The latter now boast the fastest growth in ICT penetration and related productivity growth has surpassed that of developed and transition countries. Today, public information and services that were difficult to access a decade ago are readily available especially to rural and marginalized communities in Sub-Saharan Africa (SSA). In remote rural locations in SSA where communication would normally take several weeks to complete, the advent of mobile phones, instant short messaging system (SMS) and multi-media message system (MMS) has eliminated waiting periods to relay important decisions. Modern ICT such as Internet, email, 3G and 4G mobile phones, personal digital assistants (PDAs) and social networking via Youtube, Twitter, MySpace, Facebook, etc. have extended the communication frontiers in the 21st century reaching previously excluded communities. These modern ICTs have enabled developing countries to "leap-frog" agriculture and rural development. As a result increasing attention is being focused on the role ICT could play in promoting access to markets that is critical to the achievement of agricultural commercialization, food security, and poverty alleviation in SSA [14]. Mobile phones may help to increase income, improving the efficiency of markets, reduce transaction costs, and provide an opportunity for interventions in service delivery [8].

Internet of things (IoT) is a technology occurrence that is influencing the current context and will influence the future context. The idea of IoT relates to creating a network of objects that communicates with one another, via the internet, integrating embedded sensors, RFID, GPRS, computers, actuators, mobile phones, etc. These objects have unique addresses that enable them to address and verify their identities. The objects exchange and process information according to defined tasks and send reports to users[2]. IoT capabilities of interlinking objects through the internet can possibly be used in agriculture in several scenerios.

Several researchers addressed the use of IoT in agriculture to enhance the different agricultural processes. Xiaojing and Yuangua (2012) [25] emphasise mostly the use of cloud-enabled systems to show the relationship between the information cloud and IoT from the view point of agricultural data and its use cases. They argue that the intelligent agriculture is one of the applications of Internet of Things (IoT), which has an extensive application and bright future.

ZigBee is a low-cost, low-power, wireless mesh networking standard [24]. The low cost allows the technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range. As a brand-new information acquisition and the processing technology, the ZigBee has seeped gradually into the agricultural environmental monitoring domain. The ZigBee technologies allow the identification of pests in the crops, drought or increased moisture. Having such information at a real-time interval, automated actuation devices can be used to control irrigation, fertilization and pest control in order to offset the adverse conditions. This technology can be applied for wireless applications in agriculture. The ZigBee nodes can obtain the temperature, humidity and illumination information in real time, and then transfer to a remote monitoring center.

A study made by Joe-Air Jiang (2014) [12] shows that precision agriculture (PA) has become an important issue. Wireless sensor networks (WSNs) and IoT might be great tools to monitor environmental parameters and plant growth in

agricultural applications, because these two technologies can provide high-resolution spatiotemporal sensing data extracted from real world physical/analog signals. Precision agriculture is concerned with whole farm management aided by the information and communication technology (ICT) to optimize returns on inputs while preserving resources with regards to crop science, environmental protection, and economics aspects [16]. Thus, vital information can be provided in terms of farm record keeping, improve the decision making, foster a greater traceability process, and enhance the inherent quality and marketing of farm products.

Maumbe (2010) [14] presents a framework of the evolution of information and communication technology (ICT) applications in agriculture and rural development based on comparative experiences of South Africa and Kenya. The framework posits that full deployment of ICT in agriculture and rural development will be a culmination of several phases of changes that starts with e-government policy design, development and implementation. The author argues that ICT use in agriculture and rural development is a powerful instrument for improving agricultural and rural development and standards of living throughout Sub-Saharan Africa. However, success in greater application of ICT in agriculture will require addressing impediments to adoption and diffusion. Such impediments include the lack of awareness, low literacy, infrastructure deficiencies (e.g. lack of electricity to charge electronic gadgets), language and cultural barriers in ICT usage, the low e-inclusivity and the need to cater for the special needs of some users. The work reviews successful applications of ICT in agriculture and urges greater use of ICT-based interventions in agriculture as a vehicle for spurring rural development in Africa.

VI. Benefits of IoT in agriculture

The purpose of this research is to identify and gain an understanding of the needs of South African and Zambian rural areas and what interventions can be provided in terms of internet of things technologies (IoT). IoT technologies have the potential to alleviate poverty and uplift the standard of living of the rural farmers. For example, organic greenhouses make it possible to grow a wide range of crops that can not only be consumed locally but also for export to other countries. This enables farmers to generate extra income that help uplift their standard of living and also to contribute to the gross domestic product (GDP). The rural farmers can also leverage the investments in the IoT technologies that support agriculture to improve the standard of living. For example the tapped solar and wind energy can be also be used not only to light houses but also to stay in touch with current affairs through radios and television sets.

With IoTs it is possible to run public agriculture surveillance programmes which enable decision-makers to guide agriculture interventions, e.g., to prevent the spread of plant eating pests, other plant diseases or alerting farmers of veld fires approaching their fields. This helps the farmers to take preventive measures before the situation gets out of hand. Without such interventions, the governments of both countries can spend lots of money in helping the affected farmers.

Precision agriculture can lead to bumper harvests even during times of drought. The governments of both countries will not spend a lot of money importing agriculture products from other countries since the farmers will produce enough farm products to feed the nations.

Since IoT technologies facilitate the tracking of farm products all the way to their destination, this is ideal for farm products that require further processing since the buyers can know in advance when the farm products will arrive and plan for the next processing steps in time. Since rural communities are sparely populated, transportation of farm products can be a problem. IoT technologies can empower the transporters by providing them with information of farmers who require transport. Therefore transporters do not need to wait until they have a full truck load of farm products to start off, they can leave any time provided they are aware that there are farmers waiting for transport ahead.

Through the use of Near-Field Communications (NFC), the farmers and buyers can benefit from paperless transactions and this helps minimize on theft and fraud. Similarly this is beneficial to rural farmers who have no access to banks within a reasonable distance to deposit cash from purchases or withdraw cash to buy farming inputs.

The use of livestock or crop smart health cards which store information related to affected livestock or crops can be beneficial to both the veterinary or agriculture officer and the farmer. This can lead to efficient and effective diagnosis and prescription of medicine since the officer has access to all the historic information of the affected livestock or crop.

If satellite transmission is made available in the deep rural area, this has the potential to create jobs for local businesses who could offer low-cost solutions, access and wireless network services cheaper to the communities. Satellite transmission can also enable farmers in rural areas obtain information on markets for their products and prices, government services that they can access, and their rights. The systems can also connect to government departments and local and international markets. With the introduction of the mobile internet and low-cost sensors, farmers could interact directly with consumers and cutting off middlemen who usually exploit them. This is beneficial to farmers because they can make better profits on their products.

VII. Conclusion

This research has identified potential applications of IoT in agriculture for sustainable rural development. It has shown the business benefits that can be derived from IoT by various domains of agriculture. These domains include water management, weather forecasting, wildlife management,

finance, forestry, plant and animal disease management, transport and storage of agricultural produce, extension services, etc. The study is meant to influence policy on the adoption of IoT in rural development and agriculture. The study can also be utilised by developers of new IoT technologies to build country-specific technologies based on the identified. The rural folk will development when the technologies have been developed to support poverty alleviation and uplifting the standards of the people.

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