Enhancing Agricultural Sustainability through Crowdsensing: A Smart Computing Approach

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***Abstract*—Every country needs an efficient food production and distribution system to provide food security for the citizens and to achieve economic growth. Agriculture forms a significant part of a country's food production effort. Many factors affect agriculture production from pre-harvest to post-harvest periods. This includes factors such as overproduction, underproduction, pest and disease attacks, and market price fluctuations. A deeper analysis of these problems revealed that the root cause was farmers and other stakeholders in the agriculture domain not receiving the right information at the right time when they need it most. They need both published information such as crop varieties, fertilizers, suitable soil types and real-time dynamic information such as current crop production levels, market prices, and pest and disease outbreaks. Smart Computing offers an innovative way to generate situational information by providing published knowledge as actionable information and making users act on this information. In here, we extend our previous work to provide timely actionable information via crop calendar feature by re-conceptualizing based on information flow in Global Positioning Systems (GPS). Also, we adopted empowerment theory to create empowerment-oriented farming processes to motivate farmers to produce crowdsensed information and aggregated it to generate new situational knowledge on pest and disease outbreaks. This created a holistic information flow model for agriculture domain like energy flow in biological ecosystems enabling us to create a Digital Knowledge Ecosystem for Agribusiness. This system is now being trialed in Sri Lanka and India among thousands of farmers.**

***Index Terms*—agriculture, pest management, crowdsensing, smart computing, crop calendar**

I. Introduction

Every country needs an efficient food production and distribution system to provide food security for the citizens as well as to achieve economic growth. Agriculture forms a major part of a country's food production effort. It is estimated that across the developing world, a total of 1.2 billion people live in rural areas, depend on agriculture for their livelihoods, and live in poverty [1]. Roughly one-third of the food produced in the world for human consumption every year (approximately 1.3 billion tonnes) get lost or wasted throughout the supply chain, from initial agricultural production down to final household consumption [2]. This inevitably also means that vast amounts of the resources used in food production and associated greenhouse gas emissions are also wasted.

In the developing world often, farmers not being able to sell their harvest, and forcing them to throw it away is a commonly reported problem. This reflects the absence of a mechanism to coordinate supply and demand side of the agriculture production. Previous research has revealed that the primary cause for the problem was farmers and related stakeholders such as government, agriculture authorities, and agro-chemical companies in the domain not receiving the right information when they need it most [3]. This inability to access right information when needed has resulted in multilevel coordination failure in the agriculture domain giving rise to inefficient productivity and food waste [4].

Smart Computing is an effective method to integrate the capabilities of computer software, hardware, social media, and communication networks with digital sensors, smart devices, Internet of Things (IoT), and intelligent systems to realize various innovative applications [5]. It offers new ways to generate context-specific actionable information by reorganizing pre-published knowledge and deliver it in a way that is easy for the user to act [6]. The resulting user actions can be captured to generate the required dynamic information in real-time [7].

We have now developed mobile-based information systems called *"Govi Nena"* and *"Gyan Kisan"* for farmers in Sri Lanka and India respectively; both names meaning *"farming intelligence"* for farmers based on Smart Computing concepts to address some aspects of above-mentioned coordination failure. Recently we saw a similarity between this system and GPS based mobile navigation systems. This reconceptualisation enabled us to extend the system to deliver the best package of practice (PoP) through a crop calendar feature similar to "turn right" or "turn left" in GPS systems, and early warning of pest and disease outbreaks through crowdsensed information similar to GPS forecasting traffic congestions. This paper describes these extensions which further make coordination activities in the agriculture domain efficient. The next section describes the prior work leading to this extension. Section 3 presents the GPS based reconceptualization and crop calendar. Section 4 presents the pest and disease outbreaks detection through crowdsensing, followed by the conclusions and future work.

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II. Background – A Case Study from Sri Lanka

The background on which the new research work was conducted is presented as a case study based on a work carried out in Sri Lanka [8]. In Sri Lanka, agriculture is one of the important sectors, and approximately 33% of the total labor force is engaged in agriculture sector [9]. Coordinating agriculture production among large number of small land holdings is a major problem. The main issue in an uncoordinated agriculture domain is over production of some crops while some others are in short supply, leading to widely fluctuating market prices. An in-depth analysis of this problem revealed that the root cause was that farmers and related stakeholders in the domain did not have access to correct, up-to-date, complete information in a suitable modality and on time for optimal decision-making. Farmers need published information (quasi-static) about crops, suitable fertilizer, water requirements, land preparation, growing and harvesting methods, and real-time situational information such as current crop production levels, pest and disease outbreaks, and market prices [10]. This situational information is also needed by the agriculture department, agro-chemical companies, buyers, and various government agencies to ensure food security through effective supply chain planning while minimizing waste.

Inspired by the rapid growth of mobile phone usage in Sri Lanka, including among farming communities [4], in 2011, an international collaborative research team with members from Sri Lanka, Australia, Italy, and United States embarked on a project to address this problem. Using an iterative participatory design approach, a mobile-based artifact was developed to enhance the flow of information among stakeholders in the agriculture domain as shown in Fig. 1 [11]-[13]. This was a complex problem with many research challenges. Due to the complexity of factors that affect supply and demand in the agriculture domain, it was very difficult to identify the deeper requirements that an artifact should address to achieve good coordination between the two. Thus, the team used an iterative process building many functional prototypes and validating the relevance of these artifacts to address certain symptoms of the problem to discover the overall requirements that should be addressed [14], [15]. The different artifacts were integrated to create a new mobile-based solution that was later conceptualized as a Digital Knowledge Ecosystem [8]. This system can predict the current production situation in near real-time enabling government agencies to dynamically adjust the incentives offered to farmers for growing different types of crops. This way of delivering aggregated information helped the farmers to achieve sustainable agriculture production through crop diversification [8]. In 2016, the Sri Lankan Government announced this as a National Project in that year's Budget Speech. The system that was originally developed for farmers in Sri Lanka is now being trailed by five thousand farmers in India.

There are several insights from this project that can be gained. Firstly, this case study illustrates the implications of a lack of multi-level coordination; matching supply and demand, coordination of input supplies and selling activities. The root cause for all these was identified as farmers, and related stakeholders are not getting the right information at the right time. The case study also presented the evolution of a Smart Computing solution to address these failures. To achieve a better match between supply and demand, farmers needed to know (a) what will grow on "my farm", (b) how much it will cost to grow the crop/s, (c) what are the current production levels or what crop will likely have high demand but supply shortages? Although some of this information was available from various sources, it was not reaching the farmers in a way that they could act on it to plan their tasks. Also, information about current production levels for different crops at a given time needed to be generated in real time.

After studying the agriculture domain knowledge, an ontological knowledgebase linked to a mobile-based artifact was developed to answer the question "What will grow on my farm?" [10]. When a farmer asks the question, what will grow on their farm using a mobile application, the system captures the user's geo-coordinates to obtain the farm location and map the location to a corresponding agro-ecological zone using a GIS. Based on the agro-ecological zone, the system finds the climatic and soil parameters for the farm. Using this information, the ontological knowledgebase is queried to obtain a list of suitable crops that will grow on that farm. This is presented to the farmer on his/her mobile as shown in Fig. 2. The next question to address was: "How much it will cost to grow a crop"? To enable the question to be answered, we added expense calculator functionality to the mobile application as shown in Fig. 1 and Fig. 4. From the list of crops that will grow on the farm, a farmer can select a crop and specify the extent she/he is planning to grow as shown in Fig. 3. Then, it fetches the inputs required per unit area, such as fertilizer, pesticides, machinery labor, and seed required for the selected crop from the ontological knowledgebase and current market prices and presents the cost of production to the farmer as shown in Fig. 4. After exploring the cost of production for the different crops in the list of crops that will grow on the farm, the farmer can select a crop to grow and add it to a growing list. At this point, the system captures the crop and the area that the farmer is planning to grow.

Once statistically significant numbers of crop selections from farmers are collected, the system can start predicting the current production level thus generating the information required to answer the next question: "what is the current production levels for different crops?". The current production level information is presented to the farmer by adding a color code to list of crops; green, yellow and red for low, medium and high production levels respectively [8], [14] as shown in Fig. 2.

Once a Smart Computing solution was devised for an individual farmer, it was extended to connect all stakeholders of the domain to empower the society as a whole. This was achieved by enhancing the flow of information among all stakeholders in the agriculture domain enabling effective coordination of inputs such as fertilizer and pesticides, market linkages. This feature was named as “My offerings” in the mobile application for farmers to offer their resources to the wider community. Aggregated production information was made available to farmers and other stakeholders via Dash Boards to take informed decisions to better coordinate the activities thus creating a Digital Knowledge Ecosystem.

Figure 1. Main menu

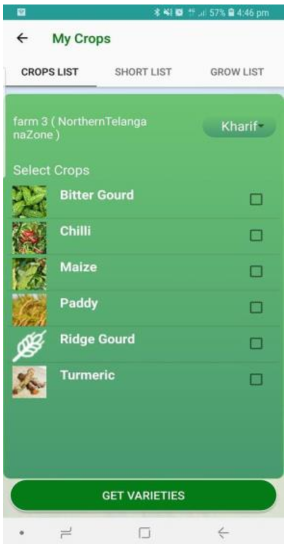

Figure 2. Crops that will grow in “my farm”

III. GPS Based Reconceptualization and Crop Calendar

From a conceptual operation point of view, we saw a strong similarity between the mobile based information system that we have developed and the GPS that is widely used today. GPS provides context-specific (in this case context is current location) actionable information in the form of “turn left”, “turn right” or “go straight” at a junction to navigate the driver to the specified location. Before GPS, the map information used in the GPS was available in printed form. GPS digitized this information using a vector-based data structure that can be searched based on geo-coordinates. This enabled the development of a wide range of navigation systems. These systems empowered more users to “go places” easily. Next GPS systems mapped user movements and using this crowd sensed information, it dynamically created traffic maps. Combining dynamically generated traffic maps with vector-based location information, these systems then evolved into directing a driver not only based on shortest distance but also based on shortest travel time. It also created a whole new rideshare industry and companies such as UBER, and OLA leading to better utilization of vehicles to meet the needs of people to “go places”.

Figure 3. Specifying the extent for calculating expenses

Figure 4. Cost summary

In agriculture, a farmer has to perform a set of major activities during the crop selection to harvesting period. These include; crop selection, land preparation, seed selection, seed sowing, irrigation, crop growth, fertilizing and harvesting. Also, farmers need timely guidance at each of these steps. Even though the required knowledge is available, the problem being it is not available in the right format for farmers to act based on it. Based on the strong similarity between the steps involved in the agriculture and the GPS, we have re-conceptualized our work, and it enabled us to see new ways to extend the functionalities of the system for farmers. It has now been extended to deliver the best Package of Practices (PoP) through a crop calendar feature similar to delivering actionable information in the form of “turn left”, “turn right” in GPS as shown in Fig 5. The crop calendar feature aggregates the scattered knowledge to one place and delivers the needful information as advice similar to GPS. Also, it sends notifications and alerts to farmers about various activities that need to be performed in the near future. Through this feature, farmers will receive timely information on “what to do next?”.

IV. Detection of Pest and Disease Outbreaks through Crowdsensing

In agriculture, one of the important problems farmers had to compete with is safeguarding their crops from harmful organisms and resulted in lower yield and reduction of crop performance. According to the literature [16], farmers’ knowledge of crop losses, causes for crop losses, pesticide selection, pesticide usages, and pesticide handling is insufficient. Sometimes, due to their low level of education, and literacy they often ignore to take preventive actions at the right time. Currently, when farmers identify the presence of pest and disease outbreaks in their field, then that particular information is not shared with nearby farming communities promptly. The unavailability of quick dissemination of such information will certainly affect other farmers since others do not have an awareness of what is going around them and it will limit their ability to safeguard the crops.

Figure 5. Crop calendar

The recent advances in ICTs have enabled a new trend called *“crowdsensing”:* a collaboration network emphasizing the involvement of human communities in the process of sensing and sharing of real-world situations [17]. It can range from personal observations to collections of similar information from larger communities of people. Most importantly, it begins and ends with people, both as individuals and human communities. This information can be acquired through the human observation and sensor enhanced devices [18]. The people tend to use smartphones to create and share such information due to the wide-spread adaptation. In here, a user can be considered as a *sensor* and the information created by the user can be considered as *sensory value*. Hence, these combinations of sensors are called *social sensors*.

Based on this concept, we have extended the capability of the developed mobile application in a way it allows farmers to report pest and disease outbreak events [19]. According to the literature, the extreme changes in weather lead to the spread of different diseases and pests [20]. In addition, there is scientific knowledge relating to the onset of possible pests and diseases during different climatic conditions [21]. During the process of reporting as shown in Fig. 6, the following information such as the type of attack, type of organism, severity level, the climatic conditions of the field will be captured through access to the farm’s location.

Then, these geo-tagged and time-stamped observations are aggregated based on location and time to find the intensity of observations at a given location within a specified time window. If the intensity in a specific geographical area reaches a threshold value and matches with the climatic conditions of the field against climatic data patterns leading to different pest and disease outbreaks, then we can conclude that the area has a potential for pest and disease outbreak. Based on our current research in [19], we considered using the weather station data to capture climatic information instead of deploying remote weather sensors, as it is available at global scale, is cost effective and shows high correlation with sensor data which is more accurate. If the system identifies that the area has a valid outbreak, then prompt communication back to the farming community is established with the delivery of required actionable advice. With such insights, it is possible to alert the farming community as early as possible. So, it will give farmers more time to take necessary precautionary actions to further minimize crop losses due to pest and disease outbreaks.

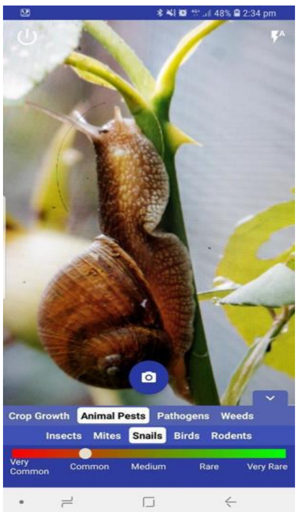

Figure 6. Pest and disease reporting screen

V. Conclusion

Due to the multilevel coordination failure observed in the agriculture domain, farmers and related stakeholders are not provided with the right and up-to-date information at the right time leading to ineffective food production and food waste. Also, it limits farmers' ability to plan their activities effectively and take the right actions at the right time. Especially in cases of pest and disease outbreaks this lack of timely information can completely destroy the crops. To overcome this failure, we have developed a mobile-based information system for farmers to enhance the flow of information among farmers and other stakeholders in the agriculture domain. In this work, we have extended our current work as a smart computing framework by re-conceptualizing our previous work to deliver Package of Practice (PoP) as actionable information via a crop calendar feature. Also, we have adopted a crowdsensing approach that allows the farmers to report pest and disease outbreak events which then after processing based on threshold levels is used to generate alerts for the farming communities at risk in real-time to safeguard their crops before any losses. In the future, this can be extended to predict various activities in the agriculture domain including government to monitor the resources required for sustainable agriculture production and to predict possible pest and disease outbreaks early as possible depending on the context.

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