Unleashing the Potential of Machine Learning and IoT in Cyber Physical Farming

Mallesham Dasari, Sergey Madaminov, Sagnik Das, Santiago Vargas
Computer Science Department, Stony Brook University, NY, USA

***Abstract*—In this work, we propose CyberKrisi, a machine learning based framework for cyber physical farming. IT based farming is very young and emerging with numerous IoT devices such as wireless sensors, surveillance cameras, drones and weather stations. These devices produce large amounts of data about crop, soil, fertilization, irrigation as well as environment. We exploit this data to assess crop performance and compute crop forecasts. We envision an IoT gateway and machine learning gateway in the vicinity of farm land which performs predictions and recommendations as well as relays this data to cloud. Our contribution are twofold: first, we show an application framework for farmers to provide an interface in understanding Farm data. Second, we built a prototype to provide illiterate Farmers an interactive experience with Farm land.**

***Index Terms*—Agriculture, IoT, Machine Learning, TV Whitespace Network, Cloud.**

I. Introduction

Agriculture is one of the important industry that needs to be improved to feed rapidly growing population. Demand for food is going to be doubled by 2050 [1]. Improving the yield requires Farmers to understand the crop performance with respect to season, soil and environment. Precision agriculture has already shown using sensor measurements of soil for varying water intake improves 50% farm productivity and reduces 35% water intake [2]. Other measures such as nutrients suitable for soil and crops suitable based on season are useful. Precision agriculture comprises of Information Communication Technology (ICT), Internet of Things (IoT) and data analytics platform to understand the issues related to crops, soil and weather conditions.

The crop performance can be observed under different practical conditions such as the quality of soil, weather conditions, surrounding environment and neighbor Farm lands, using studies like phenotyping by observing the pH levels of soil, the rate of Nitrogen depletion. Currently, these studies are carried out on real-world farming fields and manually taking the measures for irrigation and fertilizers. Automating the time series data collection and processing will decrease the cost and improve the efforts in interacting with Farm land.

IoT devices has the ability to understand soil characteristics such as pH levels in soil and Nitrogen content depletion, thereby recording this data over time series and transmitting to farmers for further analysis. Furthermore, recent trend in deploying aerial vehicles such as drones collect rich set of data in terms of images and video which gives much more realistic view of field virtually. Sharing these images and video using interactive applications over mobile phones, Farmers map their Farm lands to monitor crop anomalies remotely. On the other hand, Dairy cattle has already started using cutting edge technology such as software defined food bunkers, robotic milkers, accelerometer based Fitbit kind of devices to keep track of animal health conditions such as illness, fitness or even pregnancy. This brings altogether a variety of IoT traffic characteristics in Farming arena where wireless communication plays critical in handling this data.

Upon receiving data from these devices, the IoT gateway must process the data intelligently for final conclusions. Recent success of Machine Learning (ML) algorithms opens more doorways for improving the yield by learning more from the data analytics. By recording more historical data every year in the cloud, the accuracy of learning algorithm can be improved greatly, consequently giving optimal recommendations to Farmers.

A. Issues and Challenges

Precision agriculture is a complex ecosystem involving ICT, Biological infrastructure and agribusiness etc thereby introducing bottlenecks in terms of network, hardware, complexity of applications. For instance, drones collect image and video data then transmit to nearby IoT gateway, which requires a high bandwidth link and processing hardware with low cost. Huge volume of sensor data also requires reliable Internet connection at the IoT gateway to relay the data to cloud. Using Cellular network is feasible solution but not cost effective. Furthermore, the Cellular Internet data rates are not so sophisticated at the Farm fields. Another issue raises in detecting and diagnosing failure of these IoT devices in terms of power failure, malfunctioning etc. In designing CyberKrisi, we identify three key challenges: 1) Connectivity and Computing costs, 2) Powering of devices and 3) Heterogeneous data processing.

First, wired communication is not feasible in fields because of aerial constraints and non-deterministic farm planning. Hence, to provide a reliable, low-cost and high bandwidth network, CyberKrisi exploits TV wireless spectrum. FCC released unlicensed TV whitespace for secondary use which has greater impact in rural areas. All IoT devices connect to this network using WiFi back-haul. Hardware is second most important component in terms of cost and corresponding processing capabilities. Low-cost hardware leads to unreliable life of devices and slower processing of data thereby choking real-time communication. Second, power availability is not guaranteed in fields which makes it more challenging in addressing Availability. Currently, solar panels provide enough power in good weather conditions but it is not reliable because of cloudy environments. At last, the heterogeneous data generated from different devices such as drones, sensors and Fitbit tags should be processed in different categories and build multiple ML models which makes CyberKrisi a complex ecosystem.

B. *Related Work*

There is an extensive notion prior work on precision agriculture, smart farming and software driven farming using wireless sensor networks. Past work [5][8][11] has explored deploying sensor networks in Farm lands to extract soil and crop information such as temperature, humidity, pH levels and Nitrogen levels. These methods were relied on poor network conditions and does not support rich data generated by drones and cameras. Further, these methods lack cloud backup connection and are vulnerable to bad weather conditions. Farmbeats [4] proposed an IoT based data driven agriculture with more reliable and high bandwidth network (using TV whitespaces). This method addresses challenges such power constraints, connectivity and making drones communication effective specifically image and video processing. Farmbeats leverages whitespace network [10] to provide high bandwidth link between Farmer's home and fields. However, the system does not address the front-end application framework for illiterate farmers. On the other hand, precision agriculture studied crop psychology, agri science [9] by leveraging ICT. Data driven techniques [6] have studied deep understanding of Farm data thereby forecasting and giving recommendations to farmers using smart-phone application frameworks. Phenonet [3] is another major study deploying sensor network over fields collecting large scale data analytics.

Our work focuses more on farming in developing countries where 37% of population are illiterate in India and more than 50% in African countries [7]. CyberKrisi is an end-to-end cyber physical farming platform for Farmers, Scientists and agronomists with a key focus on improving efforts of illiterate farmers.

II. System Design

We choose following decisions while designing CyberKrisi:
Experience: Farmers should have good Quality of Experience (QoE) while interacting with Farming land. Understanding the root cause of QoE issues in CyberKrisi is non-trivial because of the number of stages (such as sensors, network, cloud, mobile devices) involved in the data delivery path.
Availability: The system should provide uninterrupted services. Farmers should be given access to data irrespective of system issues such as network failure, power outage and bad weather conditions. The IoT gateway should relay incoming data, predictions and recommendations to cloud at a frequent interval. Cloud connectivity makes it possible but it should not provide over-stored data which leads to inconsistent experience.
Scalability: The performance of the system should not be affected with increase or decrease in number of devices communicating in the system. The size of data generated is very specific to device. For instance, sensors generate a few bytes for second whereas devices such as drones collecting images/videos of crops and soil generate mega bytes of data provided the drones have efficient image/video compression techniques (such as H.264/5 video codec). Another aspect of scalability is to guarantee performance irrespective of number of farmers communicating with Farm land or area of Farming land or the number of animals in the case of Dairy.
Global Access: The farmers should be able to access data from anywhere on the globe. We introduce two new terms intra-farming and inter-farming. CyberKrisi envisions communication between Farmers and farming land as well as in between farming lands. Intra-farming provides the services only from the farming land owned by Farmers. Whereas Inter-farming access the data generated from one farming land and gives access to other Farmers. This access should be geographically distributed and subjected to multiple administrative policies. Integrating data from one farming land with another improves the performance of the system with better predictions and recommendations.
Reliability: As the Farmers are not physically observing the Farm, there could be potential damage to crops, soil and even the devices in the Farm land, if they are interacting with unreliable data thereby taking unintended measures. Machine learning algorithms should have enough historical data to achieve high accuracy so that Farmers are given reliable recommendations for crops, soil and Dairy.

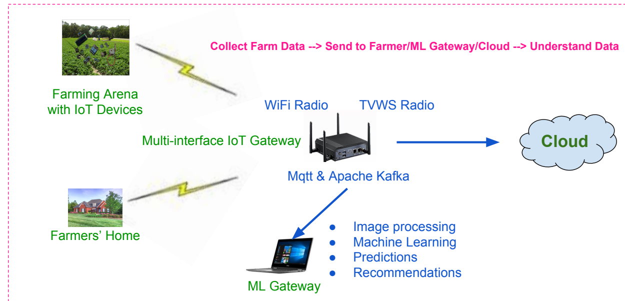
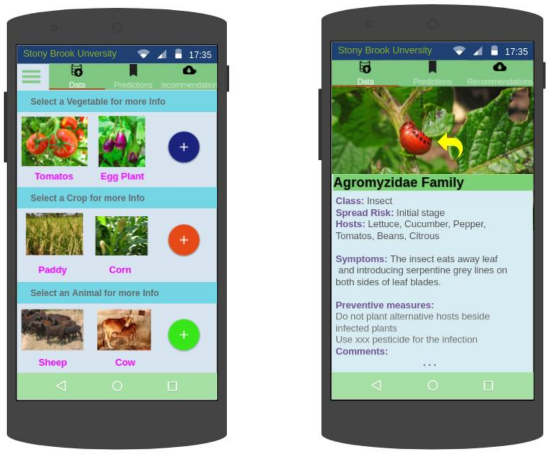


Fig. 1: CyberKrisi System Architecture

A. *System Architecture*

The system contains following components:
Farming Arena: Farmers deploy sensors, cameras and drones on Farm land. Sensors generate Farm data periodically and transmit to IoT gateway over WiFi. Cameras and drones monitor Farm land by taking images/video periodically transmitting to gateway. However, image/video data requires huge bandwidth, in that case, CyberKrisi uses multi-hop mmWave radios. As most of the devices are static in position and could be in line of sight, mmWave or even free space optics (FSO) networks are highly feasible.
IoT Gateway: IoT gateway receives data from Farm land and relays this information to Farmer's home, ML gateway



(a) (b)

Fig. 2: Two Application Screens Showing Options to Farmers

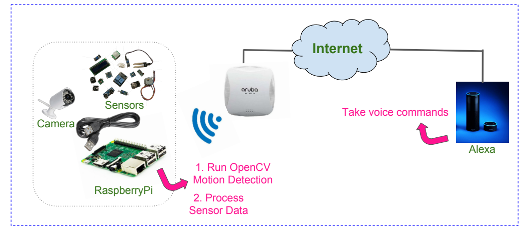
as well as to cloud over Whitespace network for further data processing. This could be a computer/laptop sitting in the environs of Farmer's home, having multiple network interfaces (mmWave or FSO, TVWS and WiFi).

ML Gateway: ML gateway is a high performance computer which processes data coming from IoT gateway to predict and recommend the crop, soil and other Farming information. ML gateway should be able to decide if the data requires different ML models for different data and react autonomously. For instance, data coming Dairy Farm might be suitable for one ML model (Neural Network) whereas data from crops and soil might require another ML model (a decision tree possibly, because of fewer parameters)

Cloud Services: Cloud services provides several advances in using this Farm data. First, it enables global access to data. Second, it backs-up the data for very long time thereby helping ML models for accuracy.

Alexa Framework: CyberKrisi uses Amazon's Echo to monitor and control Farming environment with interactive voice commands. This is particularly important in developing regions such as India and African countries, where more than half of the Farmers are illiterate. Farmers can talk to Alexa to inquire Farm land (e.g, motion detection in camera capture can be periodically transmitted to Alexa interface thereby Alexa responding to Farmer's inquiry about intrusion at Farm land).

Typically, Farmers experience poor Internet connectivity. Using Cellular network introduces several issues in terms of cost and scalability. The cellular data rates are not enough to handle video data coming from multiple drones in Farm lands. WiFi could be used to some extent to connect the Farmers' home with IoT gateway. However, the camera and drone image/video data requires high bandwidth links. Therefore, TVWS network can be exploited to improve the connectivity in Farm lands.



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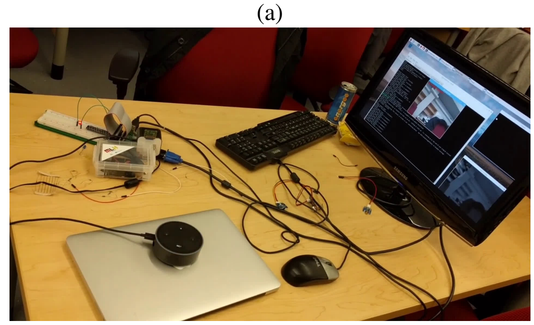

(b)

Fig. 3: The Alexa Echo Framework with IoT Devices: a) A prototype of how our Alexa framework looks like, b) Our set-up with few sensors, LEDs, RaspberryPi and Alexa

III. Prototype Development

As an initial step in developing this ecosystem, we provide two contributions: First we develop an Android application for the Farmers to provide easy access to Farm data, predictions and recommendations. Second, we create an Alexa framework to provide interactive experience for the Farmers through voice commands.

A. Application Framework

The application provides several options for Farmers about the Farm data. It interacts with ML gateway to get the predictions and recommendations about crop and soil. Fig. 2 shows two sample screens on a Nexus-5 Android studio emulator. First screen shows options for crops, vegetables and Dairy cattle. Second screen shows an insect artifacts such as its symptoms, preventive measures and comments. Typically farmers use yearly data in managing cultivation. The application provides a link to provides an interface to view previous years data. Another interesting feature we add is to keep track of employees (aka labors) in Farm work and the type of equipment needed. The Farmers can easily record the cost of cultivating and return on investment using this full-fledged information.

B. A practical case for Illiterate Farmers

CyberKrisi envisions a practical interactive Farming solution for illiterate farmers. We use Amazon Echo framework for interactive communication and integrate it with IoT devices as shown in Fig. 3. As we do not have much IoT infrastructure that is deployable in real Farm land, we build a prototype using few devices and conducted Lab experiments. We connected a surveillance camera and LED sensors with RaspberryPi3 which is connected to a WiFi AP thereby communicating with Alexa. Here, it is worth mentioning RaspberryPi can be thought of as an IoT gateway in the Farm land. We use RaspberryPi3 to run Amazon Echo APIs for interactive voice control, OpenCV libraries for image processing applications such motion detection and Node.js back-end component for integration. To make it more practical, we experimented with voice commands such as *"Hey Alexa, Is there any intruder in the Farm field?"* for which Alexa responds if there is any intrusion using motion detection in the camera capture. The project demo in the attached video shows a practical case of this framework.

IV. Conclusions and Future Work

Traditional Farming can be largely improved with the recent success of ML and IoT applications. We propose a low-cost end-to-end platform for interactive Farming solutions. CyberKrisi exploits TVWS, Echo Automation, ML models, and recent communication technologies. Our contributions are two-fold: we built an Android application which provides an interface for Farmer in understanding the Farm data and reacting accordingly. Second, we developed a prototype for illiterate Farmers using Alexa AWS micro services to provide interactive experience with Farm land. We would like to extend this framework by adding more sensors and real Farming devices in the field and understand the Farm data.

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