An Internet of Things (IoT) solution framework for agriculture in India and other Third World countries

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***Abstract* — Modern agricultural solutions have been, mostly, developed with focus on "Western farmlands". However, there are severe disparities between farms in India and those in, for instance, Europe. Applying Western solutions in the Third World will not work. In this context we have developed prototype of an IoT simulator capturing situation in Indian agriculture.**

Keywords – agriculture, Internet of Things (IoT), India, smart power management, wireless sensor network, architecture

I. Introduction

A lot of work has been done in Internet of Things (IoT), e.g. in Home and Building, or Manufacturing, automation. However, only few areas have been explored by IoT in Agriculture, especially in India. Interconnected devices, making decisions, based on processed in real-time information, as well as the past, have can seriously increase productivity. Agriculture, has wide range of activities that can be optimized. However, only few were considered by industry or academia. Here, challenges, such as limited supply of resources (e.g. water and nutrients), overdependence on human labor, need to be addressed. Especially, since 95% of agriculture is carried out manually in countries, like India, Mexico and others [1].

Existing solutions for indoor, or large outdoor farms, are costly, but efficient due to scaling. However, IoT will face different challenges in Third World agriculture. For instance, farmers, in some areas of India, barely get 4 to 8 hours of electricity a day. Moreover, some areas have no Internet. According to a recent survey by Telecom Regulatory Authority of India, presence of Internet in agricultural areas remains below 10%. Moreover, it is limited to E or 2G. Finally, many well-known solutions are too expensive, for small farms.

In this context we report an attempt to develop a simulator of IoT farming, geared towards Third World countries. This simulator was implemented using the Unity engine and tested in selected basic scenarios. It is modular, so it can be further developed to facilitate more complex scenarios.

II. Challenges

Agriculture is one of the largest industries of the world. It affects all citizens alike [1]. In India, agriculture accounts for employment of almost 50% of citizens and contributes 14% to the GDP [2]. However, it faces a number of critical challenges:

A. ***Fragmented lands.*** *In India, total area under cultivation, is around 141 million hectares. However, ~90% of farms are not economically viable, due to fragmentation [3] resulting from division of land during inheritance. Small farms do not take advantage of modern farming equipment (including irrigation).*

B. ***Lack of sufficient irrigation facility.*** *Only one third of India's cultivated area is equipped with irrigation facilities. The rest is heavily dependent upon seasonal monsoon rains. Any rain irregularity, such as delays or draughts, destroys crops along with the livelihood of farmers [4].*

C. ***Over-dependence on traditional crops.*** *Farmers cultivate mostly traditional crops, e.g. wheat and rice, with seeds rarely of high yielding variety. Moreover, no consultation is done, by the farmers, to check health of their soil and its suitability for different (traditional and modern) crops [5].*

D. ***Lack of storage facilities.*** *Products degrade due to lack of proper storage, resulting in heavy decline of potential income. Available storage spaces are reminiscent of colonial era, lacking proper monitoring of parameters such as infestation and moisture to prevent produce from spoilage [6].*

E. ***Supply channel bottlenecks.*** *Third World countries have problems caused by "middlemen" having power over farmers. Lack of quality transportation, and information of commodity prices, coupled with non-calibrated measuring apparatus, compels farmers to make distressed sales. Here, farmers may not be able to earn back their initial investments [4].*

In India, in 2012-14, ~$6 billion worth of produce was lost, while in 2016-17 the loss was ~$13 billion. Indian farms yield ~30-50% less than those in the West [3,4]. This is caused by, among others, challenges listed above. Hence, the need of solution(s) that increase efficiency of agriculture and earnings of farmers [5]. These are problems across the Third World [6].

III. State of the Art

In this context let us consider recent publications. Authors of [13,53,62,64,65] discuss merits of Internet of Things, with

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use cases related to agriculture. Next, [19,20,57,59,61] discuss strategies for digital agriculture and related information services for rural and urban areas. Authors of [21] even suggest tourism as a method for enabling agriculture. Here, farming activities are turned into experience for tourists, resulting in profits. Tactics and ideas to achieve sustainable development are discussed in [27,52]. Authors of [28] discuss use of AI to better understand metrics and to make optimal decisions, whereas [40] considers use of augmented reality for the same. Use of emerging technologies is to enable farmers to make informed decisions, while risk is removed by simulations [49]. Authors of [36] have laid out plans and prospects of agriculture done on wetlands and marshes. In [42], authors have targeted poverty as the root cause of the abject conditions of farmers, and suggested how low cost IoT can be combined with governmental subsidies to uplift conditions of farmers. Authors of [45] discuss usability, for knowledge discovery, of data from IoT sensors, analyzed, using Big Data software, e.g. Hadoop.

Authors of [48] discuss a water management system for precision agriculture. Here, wireless sensor networks are applied to regulate irrigation. In [30], detection of heavy metals using sensors in agricultural soil is elaborated, while authors of [44] use neural network, with a gradient descent, to predict soil moisture content, needed for precision agriculture. Optimal scheduling algorithms for spraying pesticides are suggested by authors of [9,63]. Furthermore, [43] proposes an advanced model for analysis of pesticide spraying patterns. Results from [43] can be coupled with those from [9] or [63]. Authors of [15] discuss and simulate methods of efficient harvesting in precision agriculture, but their approach has not been deployed in real world. In [16], a temperature sensing system to monitor grain storage is proposed. Authors of [14,54] elaborate various transportation models and use simulation to generate insights. Results found in [17] concern surveillance and its importance in precision agriculture. In [38], use of cameras and [41] use of aerial drones, for remote sensing and monitoring, are proposed. Waste management is considered in [46]. Here, an IoT framework to efficiently manage farm waste is introduced.

Authors of [23,37,50,51] discuss aspects of precision agriculture: modelling of sugar cane production, use of rovers, low altitude images, and decision support systems. In [8], an IoT based monitoring system for a greenhouse is proposed. The objective is to control climatic conditions, needed for each crop. Here, sensors collect parameters such as temperature, CO_2, sunlight, etc., allowing the system to actuate use of fans, shades, sprinklers, etc. Authors of [11] analyzed crop growth models in facility agriculture and applied sensor networks to monitor the complete growth cycles. Xufeng Ding et.al. (in [10]) proposed a model for warning-based crop protection weather module. They applied monitoring of weather changes via sensors and conveyed warnings to farmers when a critical value was observed. In [39], use of e-bots, powered by solar energy, to do various agricultural activities, is proposed.

Authors of [12] address development of a sensor network for an agricultural IoT. Here, agriculture can be connected to an IoT PaaS, allowing one to create links among agronomists, farmers and crops regardless of their geographical difference [18,20,22]. Similarly, in [26,29] agronomists will be provided with better understanding of crop growth models, while farming practices will be improved. Authors of [32,34,35,48] report on the design of sensor networks to connect agriculture to the IoT. Reliability, management, interoperability, low cost and commercialization of IoT are considered in [55,56,60].

IoT depends on sensor networks and thus it is essential to ensure that Quality of Service remains in optimum range so that the network can function at its best. In [7], modelling of QoS in IoT is discussed. It is very important that different IoT platform can effectively communicate and exchange data. Authors of [24,25,31,33,47,58] discuss different ontologies such as task ontology modelling, data analytics and sharing and using cloud ERP in the context of IoT in agriculture.

It should be noted, however that majority of these solutions do not consider challenges outlined in Section II.

IV. Proposed approach

To address these challenges, we propose a fog-like architecture, which consists of four virtual modules: *sensors*, *devices*, *actuators*, and *central hub*. It is assumed that *sensors* are "weak" (cheap) and have "weak" (cheap) batteries. They wake up, sense, send data, and go to sleep. Their behavior may be adapted, e.g. sense more or less often. They send very simple messages (the simpler the sensor, the weaker it is, the simpler/shorter/smaller the message). *Devices* are more powerful. They collect data from *sensors*. While they can complete some calculations and issue commands to *actuators*, they are still "relatively weak". *Actuators* act on commands from *devices*. They are capable of carrying tasks, e.g. pulley motors, water control switches, etc. *Central Hub* acts as "the brain", and can perform machine learning on data collected by *sensors* (sent via *devices*), and data from online APIs and databases. Figure 1 summarizes the architecture. Modules interact with each other via *Central Hub*. *Devices* collect data from *sensors*, and send it to *Central Hub* for processing. Based on the processed data, *Central Hub* may instruct *actuators* (via *Devices*) whether/when to schedule new activity, or if schedule of existing activity is to be adjusted (including deleting it).

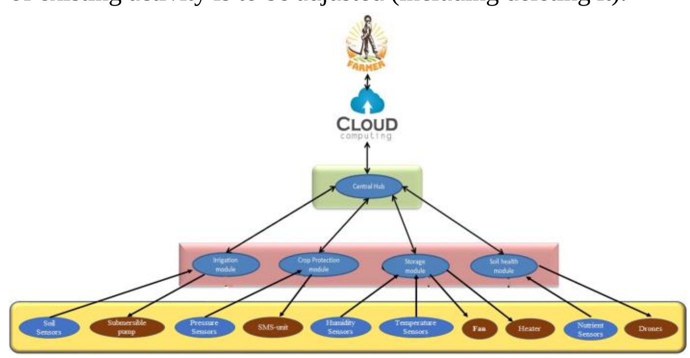

Fig 1: Proposed architecture model

The proposed architecture has been turned into an initial version of a simulator, to check basic mechanisms and interactions. Note that, since we do not have access to real data, the *machine learning* aspect, of the proposed approach, has been suggested, but has not been simulated. Note that running machine learning on simulated data would raise serious methodological issues, which should be avoided.

In the simulator, since the architecture is quite generis, we have decided to introduce *Virtual Modules* (VM) that deal with specific aspects of crop management. These are: *Irrigation*

VM, *Soil Health VM*, *Crop Protection VM* and *Storage VM*. Work of a *VM* is depicted in Figure 2.

A. *Irrigation VM* – responsible for irrigation related activities. It could be constructed around an Arduino board. A compatible generic Wi-Fi add-on module may be added for VM-CH and VM-VM communication. Reliable, high capacity rechargeable power source should be utilized. Humidity sensor collects data as frequently as needed. The *VM* is to be connected to the *actuator* of the irrigation subsystem, e.g. a submersible pump.

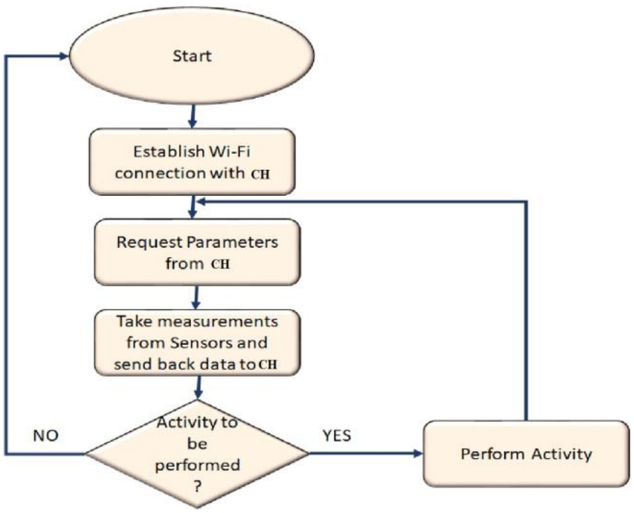

Fig 2: Flowchart for virtual (VM) modules

B. *Soil health VM* – responsible for soil quality management. Soil nutrient *sensors* are to be deployed to measure its parameters. Whenever a *sensor* records a problem, its geolocation data is to be sent to the nutrient dispatch drones. Drones use the geolocation data to sprinkle nutrients. Generic micro drones can carry loads of up to 2 kilograms. Soil health *VM* are to be built as an add-on of the *Irrigation VM*.

C. *Crop protection VM* – responsible for crop protection. It shall be developed using an Arduino board as base. A compatible generic Wi-Fi add on module may be added for VM-CH communications. A reliable, rechargeable, high capacity, power source shall be utilized. Pressure sensors are utilized, to alert farmers about presence of a potential intruder. An Alarm can be configured to play different tones, in case of humans and animals, based on the measured pressure.

D. *Storage VM* – responsible for produce storage management. It can be built around the same hardware as *Irrigation VM* and *Crop Protection VM*. Different sensors for: water detection, humidity, temperature and pressure can collect data inside the storage area. The *VM* can be connected to various *actuators* within storage space to manage its parameters.

E. *Central Hub* (*CH*) may be built around a Raspberry Pi board. Since major computations are to be done in cloud services (e.g. Azure Cloud), Raspberry Pi is sufficient for the in-situ requirements of Indian agriculture. Arduino is not advised to be used in place of a Raspberry Pi, as several VMs are to be concurrently monitored and instructed, and this unduly complicates the, simplicity-oriented, architecture. It is to be connected with an uninterrupted power supply and to the LAN port for internet connectivity. Wi-Fi module may be utilized to enable inter VM and intra CH communication. For memory storage, a high capacity class 10 Micro SD can be used. The operation of *CH* is represented in Figure 3.

V. SIMULATIONS

The, mentioned above, simulator has been build using Unity 3D engine version 2017.4.8f1. 3D models of various elements were created in Blender software. All entities and sources are either original creations or open-sourced. Scripting was done in Unity C#. The main / basic scene of the simulation is represented in Figure 4.

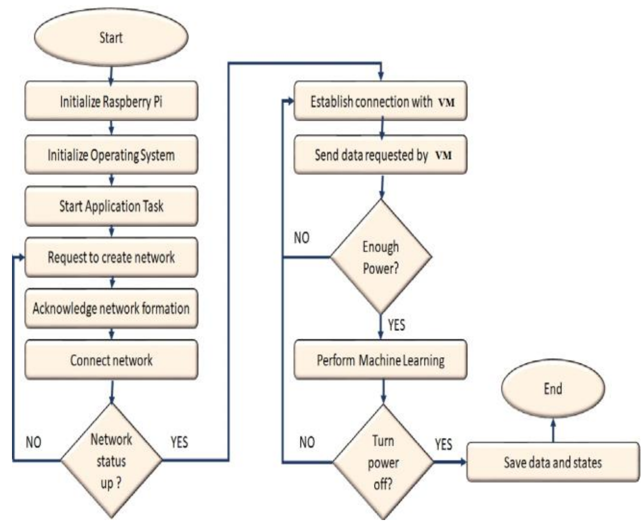

Fig 3: Flow Chart for Central Hub Software

Fig 4: Main scene of simulator showing various controls

Here, we can see the whole simulation environment. The farming lands are brown colored and the non-farming lands are green colored. A broken fencing with several vulnerable points has been simulated to mimic real life scenarios. A pond can be seen on the top right corner of the plot. It acts as the main source of water for irrigation. Farmer's house, his cold storages (silos) and his barns are on the left side of the plot. Several animals can be seen roaming across the plot in a random manner. The developed simulator has been tested on a number of scenarios. Let us report selected simulations.

Scenario 1. This is the most basic scenario. Here we consider the *Irrigation VM*. During irrigation, crops are provided ample water for their consumption. Sprinklers are to irrigate crop patches in regular intervals. However, they should also consider factors such as (1) amount of water needed by the crop (per day), (2) moisture "in the ground", (3) atmospheric and weather conditions, along with the topography of the farmland. Here, topography is of uttermost importance. Areas, which are elevated, need to be watered more frequently than those on the lower levels. Need for watering is evaluated within the local decision support subsystem, placed within the *Irrigation VM* (local fog-style component, where set of irrigation rules is instantiated). In this way, appropriate decisions can be made, regarding different situations that may materialize on a farm. Note that watering rules, in the *Irrigation VM*, can be adjusted on the basis of data analytics performed in the *CH.* Static depiction of performed simulation if represented in Figure 5. Here, the irrigation water has been coloring coded light blue while the water from rainfall is dark blue. See also figure 6)

Fig 5: Simulation of irrigation module

Note that is should be the case, there is no watering of the field in case when rainfall occurs. Because of the rainfall, the field already has accumulated (is accumulating at the moment depicted in Figure 6) a fair share of its water requirement. This scenario is somewhat more involved when the weather forecast is predicting rainfall to start "shortly". In this case, the next watering is done after all extra water has either been absorbed by the ground or the plants, and soil is dry, again, and in need of moisture. It can be seen, in Figure 6 that due to heavy rainfall the irrigation has been suspended. Water has been accumulated in the field and this fact can be seen through readings of humidity sensors (bottom part of Figure 6).

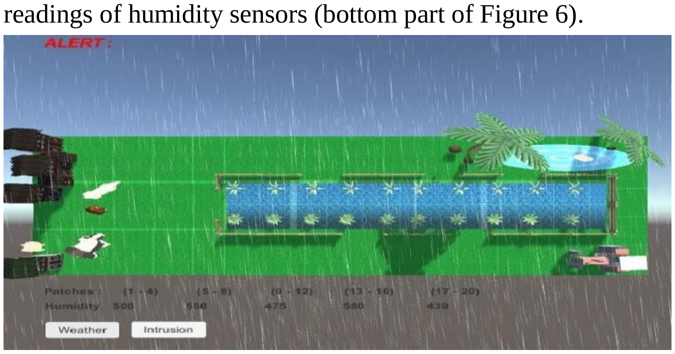

Fig 6: Weather simulation showing rainfall

Scenario 2. Here we consider the effects of weather elements, and living entities such as pests, stray animals, as well as unauthorized intruders (humans and animals). For the *Crop protection VM*, pressure sensors are simulated. As soon as they are tripped, the alarm goes off alerting the farmers. Here, it is assumed that the Alarm is a sound alarm (which is the easiest for of alerting. According to the measurements of the pressure sensor, predefined deterrent activity is undertaken. For example, weight smaller than 30 kg will trigger an alarm for dogs/cats/etc. Measurement of 50-100 kg will trigger an alarm meant for humans, while above that alarm for "large animal" will be triggered. Note that a weather-warning subsystem is also placed within the *Crop protection VM.* It is triggered in cases of hail and rainfall. As soon as it is triggered, an SMS is sent to the farmer intimating him of waterlogging in the fields. This is represented in Figure 7.

Fig 7: Simulation of crop protection module

Scenario 3. Storage is also an important aspect of the farming. The produce needs to be kept in optimal conditions to reduce spoilage. The storage module was simulated as a unit, where the conditions inside cold storages and silos like temp, pressure, humidity, etc. are sensed. The role of the system is to maintains favorable conditions by regulating them. During simulation, temperature and humidity sensors were initialized, along with two actuators, namely a fan and a heater. The *Storage VM* had preset optimal parameters for the crops inside storage area. If the readings from the sensors went beyond the optimal range, suitable actuator was be enabled to bring back the parameters into the optimal range. This is represented in Figure 8.

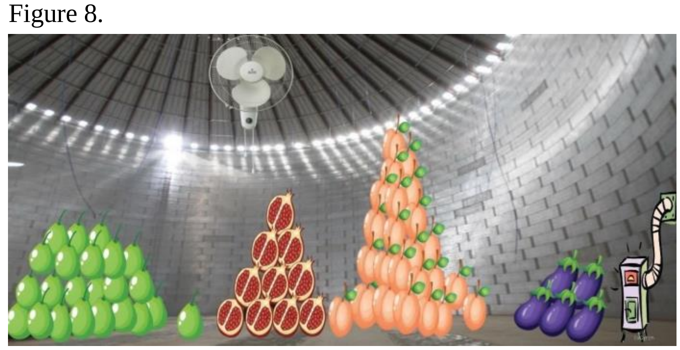

Fig 8: Simulation of storage module

VI. CONCLUDING REMARKS

Internet of Things is an emerging field. With the advent of cheap new sensors, IoT agriculture is bound to become the primary form of efficient and connected agriculture. However, it needs to be understood that introduction of IoT into the Agriculture is going to face different challenges in Western Countries and in the Third World.

Recognizing this fact, we consider an IoT solution framework for agriculture practiced in India, and in other Third World countries. The proposed conceptual approach has been implemented in the form of a prototype of a flexible modular simulator. Here, we have reported only tests with few basic scenarios. However, we have completed a much larger number of tests, which show that the initial implementation works as expected, which allows us to proceed with further development. Here, as the first step, we plan to connect the simulator to the real-world weather forecast services, to make the work of the *Irrigation VM* more realistic. We also plan to collaborate with farm specialists, to make various parameters of our model realistic and, in this way, be able to make the simulation more realistic also in this way. In a long run, we believe that the developed simulator can be used for farm development planning.

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