Implementation of IoT to Minimize Post-harvest Losses

Srishti Sahni [1], Farzil Kidwai [2], Prerna Sharma [3], Harshit Singhal [4]
Maharaja Agrasen Institute of Technology, GGSIP University [1,2,3,4]
srishti.sahni16@gmail.com [1], farzilkidwai@mait.ac.in [2], prernasharma@mait.ac.in [3], harshitsinghal33@gmail.com [4]

Abstract—**This paper analyzes the abiotic factors responsible for the post harvest losses of cereal grains. Factors like relative humidity, temperature, moisture and oxygen content of the warehouses are taken into account and their relationship with the rate of decay of cereal grains is examined. A ubiquitous sensing environment is set up using an IoT (Internet of Things) device which collects real time data and establishes a network between different sensors and actuators, reducing human interference to zero. The collected data is used to predict the approximate time within which the grains should be treated in order to avoid degradation and minimize losses. A machine learning algorithm is applied and a suitable model is constructed to achieve the same. This model evaluates the analytical and experimental data from previous researches and draws conclusions which are then implemented in association with the IoT device to generate precise results. The results are contemplated and alerts are generated accordingly.**

Index Terms — **Internet of Things, Moisture, Shelf-Life, Temperature, Water Activity.**

I. Introduction

FOOD shortage continues to be a serious problem in India. Our yearly produce is more than our yearly consumption yet we lose many lives to starvation every year. According to a report generated by the Ministry of Food Processing in 2007, agricultural produce worth Rs. 580 billion is wasted each year [1]. This amount has only increased over the years with an estimated loss of Rs. 926.5 billion in 2017. Our government also spends a considerably large amount of money for waste management of the degraded crops which only adds up to the expenses of the losses. Between 1997 and 2007, the government spent Rs 26 million just to get rid of rotten grain [1].
The population is also increasing at a tremendous rate with little or no increase in grain availability. There is a visible increase in the production rates over the years, still post harvest losses are eminent and solely responsible for the food shortage in our country. Our main objective is to target the latter and attempt to minimize it with the assistance of two technologies; *IoT* and *Machine Learning.*

A. *What is IoT?*

For years, computing has been associated with the realm of conventional desktop computers but now, IoT devices have taken over and will soon be dominating the technological world. Internet can be defined as an interconnected system of computer networks which operates using the TCP/IP protocols for communication. As of now, Internet is solely based on interaction between humans whereas IoT (Internet of Things) attempts to establish a connection between inanimate objects allowing them to communicate with each other, process and share information, compute results and act on them without human interference [2]. Every object on an IoT network from sensors to actuators are uniquely identified using Radio Frequency Identification (RFID) and work hand in hand to facilitate the design of a communication and information transmitting system that is invisibly embedded within the environment and has zero effect on the surroundings.

An IoT device has three demands for proper functioning which include a shared understanding between the users and their appliances, software architectures that communicate information to relevant objects and analytical tools which aim towards smart behavior [3].

B. *IoT in Agriculture*

Agricultural sector is slowly inclining towards IoT to implement smart farming techniques. The sole reason for this inclination is the tremendous increase in population with not much scope of increase in yearly produce. IoT provides an environment embedded system [3] which collects data to monitor the complete process from seeding to harvest as well as allows one to manage the produce post harvest [14].

IoT facilitates sensing and monitoring which aids the understanding of weather and other climatic conditions and offer a better data processing along with remote access to the farms, actuators and robots built specifically to implement precise, loss free production [12]. Despite the innumerable benefits, implementation of IoT in agriculture is still in a beginner stage with a lot of room to grow. IoT was first introduced to the agricultural sector in 2010 and has shown a remarkable growth and potential in this sector, however the applications in this sector are still insignificant when compared to that in other sectors [2].

C. *Machine Learning*

We humans have a tendency to watch, observe and learn. We base our conclusions on knowledge and experience and this quality gives us the ability to adapt. Machines on the

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other hand, work on a predefined set of instructions and are immutable to a certain extent. The science of machine learning focuses on designing a system that can learn from theoretical arguments, observational categorizations, empirical studies and practical demonstrations [4].

A machine learning algorithm creates a model based on a training data set which establishes a relationship between the surrounding factors and how the machine is expected to react in their presence. Multiple data models can be created for each problem. The main objective is to select a model which fits perfectly with the requirements of the project and can be generalized for a larger set of data. This is achieved by a simple approach of eliminating the models with obstacles that impede practical applications [4]. The resulting model is then implemented to develop an application which has practical utility.

II. Biodegradation Of Grains

Biodegradation is the disintegration of materials by the actions of bacteria, fungi or other biological means. Biodegradation in grains can be attributed to their own metabolic activity and to the actions of insects, mites and moulds which lead to the growth of bacteria and fungi [5]. Fungal deterioration, particularly due to mycotoxigenic species, is one of the major causes for post harvest degradation in cereal grains and can be dubbed as a major contributor for post harvest losses [16]. The concern over fungal invasions has increased significantly with a considerate increase in the observed mycotoxin levels of the grains over the years. This rise in mycotoxin levels is the direct result of harvesting grains at moisture levels that are too high for storage [9].

Fungal deterioration of grain is usually followed by growth of microorganisms, the breakdown of organic matter to yield $C0_2$ and H_20, and the generation of heat and loss of nutrients, which occurs due to the changes in carbohydrates, protein, lipids and vitamins associated with the grains. Grain germinability is also lost and aesthetic changes occur which include discoloration, caking and abnormal odors [9].

Fungal Deterioration is fueled by *suitable temperatures* and *high moisture contents* and keeping them in check is the only way to avoid it and all that follows. Apart from moisture and temperature, other factors such as *0_2-$C0_2$ in atmosphere*, *aeration*, *pH*, and *grain condition* interact to affect biodegradation [9].

A. Temperature

The growth in temperature accelerates the degradation process by fueling the enzyme activities within the grains until thermal inactivation of enzymes, exhaustion of substrate, depletion of moisture or oxygen, or accumulation of Carbon-Di-oxide limit the growth of microbes [9]. The factors responsible for grain degradation are so closely interrelated that determination of an optimum or limiting temperature to avoid the same is only based on approximation.

Although, there is a clear balance between safe moisture content and safe temperature for storage of grains i.e. within limits, maintaining a low temperature has a similar effect on the grains as maintaining lower moisture levels, but cold storage is an expensive approach and is not completely reliable as some microbes still grow in colder environments.

A study in 1974 suggested that A. glaucus, several species of Penicillium, Cladosporium, Fusarium, Mucor, and some yeasts grow between -5° C to -8° C, and may even sporulate at temperatures below freezing [9]. It is also observed that the grains can be stored for a longer interval of time if the temperature is lowered while maintaining the same moisture levels.

It is evident that temperature alone can not be considered as a main contributor towards reduction of post harvest losses but can be useful if working in accordance with lower moisture contents.

B. Oxygen and Carbon-Di-oxide

Grains are nothing but seeds and hence need oxygen to respire. Moisture and heat are a byproduct of respiration and can also be held accountable for the creation of a warm and cozy environment which promotes the growth of microorganisms, mites and moulds. Once these organisms begin to grow, they respire and give off heat and moisture as well, which accelerates their own growth and fuels the degradation process [6]. The warehouse has a limited amount of oxygen and an increased number of consumers limits its availability to the grains. With not enough oxygen for the grains to respire, grains begin to respire in presence carbon-di-oxide which decreases their nutritional value and allows them to taint, making them unfit for human consumption [6].

Storing grains in complete isolation can help curb microbe growth, and has a visible effect on grain biodegradation. This can be achieved by limiting the oxygen supply to the warehouse. A study in 1971 stated that reducing oxygen from 5 to 1% inhibits degradation to a greater extent, while carbon-di-oxide concentrations above 14% are detrimental to mold growth [9]. Some species of molds and anaerobic bacteria can also grow despite these harsh conditions [9] which means these conditions aren't binding and can only help reduce the problem but are incapable of extinguishing them. Maintaining such conditions has its benefits but this is not a viable solution as low oxygen and high carbon-di-oxide levels hamper the grain quality [6], are harder to maintain, and can prove to be hazardous for the workers of the institution, which is intolerable. The only way out is to make sure the warehouse has enough oxygen for all the grains in it and no other

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consumer for oxygen i.e. microbes or insects are allowed to grow.

C. Moisture

Moisture plays a crucial role in the growth of microbes and degradation. If appropriate moisture levels are maintained, grains can be stored for years with minimal or no degradation as vulnerability of the grain to biodegradation can be directly related to the moisture content of the grains. Moisture also influences physical properties such as hardness, coefficient of friction, specific weight and electrical characteristics of the grains [5].

With current farming methods, the grains which are harvested have a high moisture content which makes them unfit for long term storage. Hence, the grains are dried and moisture levels are reduced significantly before storage [9]. Maintaining low moisture levels throughout the storage period is a difficult task and once achieved can reduce post harvest losses to a much greater extent when compared to any other factors, making moisture and water content of the grains the main focus of this research.

III. Water Content and Absorption

Like every other living organism, water is also a crucial part of the plant's physiology and is actively present in every part of a plant system. Water in grains can be found in more than one forms *bound*, *adsorbed* and *absorbed* water [5]. All of these three amounts are responsible for the complete moisture content of the grain.

Bound water is the amount of water which exerts an equilibrium vapour pressure similar to that of pure liquid at the same temperature. It is a property of the grain and varies from one cereal grain to another. Adsorbed water is the water that are attached to the surface of the grains, whereas absorbed water is the amount of water that penetrates through the surface of the grains and enters them.

The water absorbed by grains depends on three key factors temperature, hardness of the water molecules, and storage conditions of the grains. A study in 1979 suggested that starch contains more pore sites for water molecules to attach as compared to cellulose. Therefore, more water is absorbed in grains with high starch concentrations as compared to the ones with high cellulose content [7].

IV. Relative Humidity and Equilibrium Moisture Content

The amount of moisture within the grain at any particular time and temperature is its relative humidity (rh). Relative humidity can be defined as the amount of moisture that can be removed from the grain with unheated air [6]. It is the basis of deciding ventilation rates and air temperature. Can be measured using a psychrometer which has a wet and a dry temperature bulb and the values of these bulbs are compared to a psychrometer chart.

Equilibrium Moisture Content (EMC) for a grain is its moisture content at which, it forms an equilibrium with the amount of water vapour in the air [6]. Each grain has a different characteristic curve between relative humidity and moisture content that is characteristic to it and is a measure of its equilibrium moisture content.

The relationship between EMC and rh is temperature dependent and can be examined with the help of the following table 1.

Table 1. This table analysis the relationship between Equilibrium Moisture Content and Relative Humidity for various grains at different temperatures

		Corn kernels				Soybean				Sorghum				Long Grain Rice				Durum Wheat			
	°C	1.7	10.0	21.1	37.8	1.7	10.0	21.1	37.8	1.7	10.0	21.1	37.8	1.7	10.0	21.1	37.8	1.7	10.0	21.1	37.8
RH	°F	*35*	*50*	*70*	*100*	*35*	*50*	*70*	*100*	*35*	*50*	*70*	*100*	*35*	*50*	*70*	*100*	*35*	*50*	*70*	*100*
25		9.3	8.6	7.9	7.1	5.9	5.7	5.5	5.2	11.5	10.9	10.2	9.3	9.2	8.6	8.0	7.3	8.3	8.0	7.7	7.2
30		10.3	9.5	8.7	7.8	6.5	6.3	6.1	5.7	12.1	11.5	10.8	9.9	10.1	9.5	8.8	8.0	8.9	8.7	8.3	7.7
35		11.2	10.4	9.5	8.5	7.1	6.9	6.6	6.2	12.7	12.1	11.4	10.5	10.9	10.3	9.5	8.7	9.6	9.3	8.9	8.3
40		12.1	11.2	10.3	9.2	7.8	7.6	7.3	6.9	13.3	12.7	12.0	11.1	11.7	11.0	10.3	9.4	10.2	9.9	9.5	8.8
45		13.0	12.0	11.0	9.9	8.6	8.3	8.0	7.5	13.8	13.3	12.6	11.7	12.5	11.8	11.0	10.0	10.9	10.5	10.1	9.4
50		13.9	12.9	11.8	10.6	9.4	9.1	8.8	8.3	14.4	13.8	13.2	12.3	13.3	12.5	11.7	10.7	11.5	11.2	10.7	10.0
55		14.8	13.7	12.6	11.3	10.3	10.0	9.7	9.1	15.0	14.4	13.8	12.9	14.1	13.3	12.4	11.3	12.2	11.9	11.4	10.6
60		15.7	14.5	13.4	12.0	11.5	11.1	10.7	10.1	15.6	15.1	14.4	13.6	14.9	14.0	13.1	12.0	13.0	12.6	12.1	11.3
65		16.6	15.4	14.2	12.8	12.8	12.4	11.9	11.3	16.3	15.7	15.1	14.3	15.7	14.8	13.8	12.7	13.8	13.4	12.8	12.0
70		17.6	16.3	15.0	13.6	14.4	14.0	13.5	12.7	17.0	16.5	15.8	15.0	16.6	15.7	14.6	13.4	14.7	14.3	13.7	12.8
75		18.7	17.3	16.0	14.5	16.4	16.0	15.4	14.5	17.8	17.3	16.7	15.9	17.6	16.5	15.5	14.2	15.8	15.4	14.7	13.8
80		19.8	18.5	17.0	15.4	19.1	18.6	17.9	17.0	18.8	18.2	17.6	16.9	18.6	17.5	16.4	15.1	17.1	16.6	16.0	15.0
85		21.2	19.8	18.2	16.5	22.9	22.3	21.6	20.5	19.9	19.4	18.8	18.0	19.8	18.7	17.5	16.1	18.8	18.3	17.6	16.5
90		22.9	21.4	19.8	17.9	28.9	28.2	27.3	26.1	21.4	20.9	20.3	19.6	21.3	20.1	18.9	17.4	21.3	20.7	20.0	18.8

V. Water Absorption in Rice

It is observed that when rice is subjected to high moisture contents, it fissures but the fissuring requires a lapse of time called the "retardation time" [7]. The retardation time is related to the variety and type of rice. For example, the retardation time for brown rice is greater than that of polished rice as polished rice absorbs more water.

Each variety of rice has a certain critical moisture content above and below which the rice does not fissure and it is crucial to maintain this moisture level in order to maintain grain quality. Temperature and environment play a very important role in the determination of this "Critical Moisture Content". Studies show that below 15% moisture content, starch gel in rice is brittle and plastic above that therefore, critical moisture content can be estimated to be about 14-15% [7]. As rice matures, the tensile strength increases, reducing fissuring to a greater extent. Thus, critical moisture content only plays a role in the initial storing stages of the grains.

Apart from the fissuring, the rise of ethanol, carbon-di-oxide, and volatile microbial metabolite content is another serious concern [21]. The ethanol levels are stable below 21% and only begin to rise at a rate of .001mg/L/h once the ethanol levels rise up to 24%. Once, the 24% mark is crossed, the rate increases by about 100 times. The carbon-di-oxide levels are stabilized within a moisture range of 17-24%. A moisture level within 17-21% can be marked as a safe zone to avoid a rise in the levels of volatile microbial metabolite content [17].

Hence, a moisture level below 15% needs to be

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maintained during the initial storing stages of rice and can be increased to about 17-21% once the rice matures.

VI. Water Absorption in Wheat

It is observed that in wheat samples, the average mycotoxin levels are about 3.2 [11]. When wheat absorbs moisture, the moisture is not always evenly distributed among the grains, i.e. certain moisture pockets are developed throughout the sample. Analysis of these moisture pockets is a must as they are the main sites of mould and fungal growth. Hence, the measurements of one humidity sensor can not be trusted in case of wheat.

Before milling, grains are tampered with to soften the endosperm and toughen it. This is achieved by increasing the grain moisture levels to 12-17%. If the tampered grains are stored for more than 16-24 hours, moulds and fungi began to grow. This observation can be used to reduce post harvest losses by maintaining a moisture content less than 12-17% throughout the storage period.

Over the years, many studies have taken place in an attempt to form a direct relationship between bacterial growth and moisture levels, though it is observed that the growth of bacteria isn't directly dependent on the moisture levels of the grains or *Relative Humidity (rh)* but rather depends on its *Equilibrium Moisture Content (EMC)* or *Water Activity* (a_w) [11].

VII. Water Activity

According to Cereal Foods World's study "The Case for Water Activity as a Specification for Wheat Tempering and Flour Production", it appears that through trial and error, those who have set current recommended moisture levels for grains and flour have fortunately, if unknowingly, pinpointed the right water activity level to maximize stability [11]. Water content alone is no measure of grain degradation as water content comprises of both bound and unbound water in the grains. The chemically bound water is unavailable for microbes to grow and hence measuring it is of no use. Unbound water is the amount of water responsible for microbe growth and hence, its measurement is the only one which matters. Water activity is a measure of the unbound water present in food particles. Hence, water activity is the most useful measure of availability of water for microbes and fungal growth [9].

Water activity is a thermodynamic concept and is closely related to Gibbs Free Energy. Unlike any thermodynamic concept, water activity has certain requirements for its measurements i.e. the system should be in equilibrium, temperature should be defined and a standard state should be specified. Pure water is taken as reference, the Gibbs energy of pure water is 0 hence, its water activity is 1.0. Water activity (a_w) is measured as the ratio of partial vapour pressure of water in a substance (p) and the standard state partial vapour pressure of water (p_o) [26] and ranges from 0 to 1 i.e. from "bone dry" to "pure water".

$$a_W = p / p_O$$

A. *Water Activity Measurement*

Water activity can not be measured directly, it requires an indirect method of measurement. Various methods for water activity determinations are detailed in the Official Methods of Analysis of AOAC International (1995) but a lot has changed since then [8]. The equipment are more accurate, faster and advanced as compared to the ones available then. Today, there are two devices available in the commercial market that can be used for water activity measurement.

i. *Chilled Mirror Dewpoint Hygrometers.* In a Dew Point Hygrometer, the temperature of the chilled surface is measured when it is at dew point. Reflective surfaces are used to determine the Dew Point state of the system, i.e. when the liquid starts to condense on the surface. A temperature range is maintained from -40°C – 30°C and the dew point temperature is usually included within this range. Low temperatures are ensured with the help of a cooling system based on Peltier heat pumps [10].
   Water activity is determined by the ratio of dew point temperature and the temperature of the sample before the measurement starts. The cooling system helps the Hygrometer to establish an equilibrium state for the measurement of Dew Point Temperature [8].

ii. *Electric Hygrometers.* An Electric Hygrometer measures the Equilibrium Relative Humidity (ERH) using a hygroscopic polymer and related circuitry that gives an electric signal relative to ERH. They can measure water activity up to an accuracy of $\pm$.01 [8]. For accurate readings, the temperatures of the sensor and the sample should be the same at all times i.e. a good temperature control or management system is required for its proper functioning.

B. *Water Activity, Microbe Growth and Chemical Degradation*

Whereas temperature, pH, and several other factors influence the growth of microbes in grains and the rate at which it grows, water activity is often the most important factor. Microbes cannot grow without "availability" of water. For the same moisture content, different substances can have different amounts of available(or unbound) water. Every microorganism has a limiting amount of water activity under which it cannot grow [26]. The water activity level that limits the growth of the vast majority of pathogenic bacteria is 0.90, 0.70 for spoilage molds, and the

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lower limit for all microorganisms is 0.60 [9]. Since mold, microbial spoilage, and lower rates of rancidity are better correlated with lower water activities than moisture contents, it would make more sense to focus on optimizing the water activity level and then confirm that the moisture content is acceptable rather than to rely on just a moisture content specification [11].

Water Activity also affects the chemical and enzyme reactivity of the grains. Unbound water may act as a solvent, reactant, or change the mobility of the reactants by affecting the viscosity of the system. High water activity also promotes non enzymatic browning, lipid oxidation, degradation of vitamins and other nutrients, enzymatic reactions, protein denaturation, starch gelatinization, and starch retrogradation [8] which leads to chemical degradation of the grains.

VIII. Shelf - Life

Shelf-life is the time period for which the grains are fit for consumption after harvest. Grains with lower shelf-lives, degrade faster accounting for more losses as compared to the grains with a higher shelf life. Post harvest losses and shelf-life of the grains can be directly related to each other and hence, if we can simulate an environment which ensures an increase in the shelf-lives of most of the grains stored in a particular warehouse, post harvest losses can be decreased to a greater extent.

Shelf-life of the grains can be attributed to certain abiotic factors, these include:

i. *Low Temperature.* High temperatures promote grain germination, insect growth within the warehouse and enzyme activity of the grains which increases the risk of microbe growth [5]. All these factors have an adverse effect on the quality of the grain and attribute to maximum losses. Hence, lower temperatures favor higher shelf-life.

ii. *Moderate oxygen levels.* High oxygen levels promote bacterial and microbe growth, whereas low oxygen levels can lead to tainting of the grains which affects their quality and make them unfit for consumption [6], therefore moderate oxygen levels should be maintained throughout the storage period in order to ensure higher shelf-lives.

iii. *Low moisture content.* An Equilibrium Moisture Content (EMC) above 12% promotes diseases. If this level increases to about 13.5-15%, fungal pores are likely to grow. Most of the aerobic bacteria grows at an EMC greater than 20%, [5] making lower moisture contents a favorable characteristic for higher shelf-lives.

A. Water Activity and Shelf-Life

Water activity can be a crucial measure in determination of shelf-life of the grains [26]. A critical high and low water activity level can be set depending on the type of grain. As the water activity approaches this critical value, the remaining time for degradation to begin or shelf-life can be computed. Temperature, relative humidity and critical water activity can aid in the development of the alert system and help achieve the task.

The water activity at which fungi cannot grow in wheat is below .70. Once the water activity reaches above .70 and is maintained, the grain begins to degrade in 16-24 hours [11].

IX. Related Works

The ever growing concern of food security and food shortage are the driving forces behind the development of IoT based solutions in the agricultural sector. IoT is an attempt to integrate uniquely identified “things” or devices with sensors, real-time internet and cloud databases in order to solve the challenges faced by this sector [2]. Many working solutions are present but there is still a lot of room to grow and progress. Some of these solutions include

i. *Developing Ubiquitous Sensor Network Platform Using Internet of Things: Application in Precision Agriculture.* Francisco Javier Ferrández-Pastor, Juan Manuel García-Chamizo, Mario Nieto-Hidalgo, Jerónimo Mora-Pascual and José Mora-Martínez attempt the integration of information and control technologies in agriculture processes to implement precision agriculture. Precision agriculture is practice that minimizes the use of resources and optimizes production efficiency by adapting common farming techniques specific to the conditions at every stage of crop production by the use of efficient technologies like micro-electro-mechanical Systems, Wireless Sensor Networks (WSN), computer systems and enhanced machinery [12]. The system breaks up the problem into three simpler tasks and target them in a particular order to produce the desired outcomes. Firstly, crop determination and data collection takes place to gain a better understanding of the crop and field conditions, this is followed by processing and analysis of the collected data in order to devise a plan of action for that particular crop and field in that very season, lastly the execution takes place which is achieved using advanced machinery and ensures complete resource optimization [12].

ii. *Internet of Things Platform for Smart Farming: Experiences and Lessons Learnt.* Prem Prakash Jayaraman, Ali Yavari, Dimitrios Georgakopoulos, Ahsan Morshed and Arkady Zaslavsky aim to devise a system to help improve the farm productivity by understanding and forecasting crop

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performance in a variety of environmental conditions in order to implement smart farming techniques. The proposed device offers crop recommendations which are largely based on field related study and collection of data using an environmentally embedded sensing network which is smart enough to reject unwanted readings and return the best possible results with least expected errors [13]. The device works in synchronization with a cloud platform that automates the collection of environmental, soil, fertilization, and irrigation data and correlates such data to filter-out invalid data from the perspective of assessing crop performance. The system is personalized and can compute crop forecasts and crop recommendations for any particular farm [13].

iii. *Agricultural Production System based on IoT.* Meonghun Lee, Jeonghwan Hwang and Hyun Yoe propose a design for an IoT device that can stabilize the supply and demand of agricultural products by a network of environmental sensors which work in accordance with a prediction system to estimate the growth and production of the crops. Earlier, the demand and consumption of agricultural products could be predicted quantitatively, however, the variation of harvest and production by the change of farm's cultivated area, weather change, disease and insect damage etc. could not be predicted making it impossible to control the supply and demand of agricultural goods [14]. The system proposed enhances the ability of farmers, researchers, and government officials to observe the complete agricultural cycle from seeding to selling and allows them to analyze current conditions and predict future harvest by correlation analysis between the crop statistical information and agricultural environment information. This not only helps conquer the demand and supply problem but also improves the quality of agricultural products to a greater extent [14].

X. PROPOSED WORK

We propose the design of an IoT device that functions in accordance with a machine learning model to handle alert generation. It is observed that both Water Activity and Equilibrium Moisture Content (EMC) can be used to determine if the grains are fit for storage or not?

A sensor network is established within the warehouse with the objective to measure the value of Water Activity for the grains using electronic hygrometers, and temperature and humidity with temperature and moisture sensor.

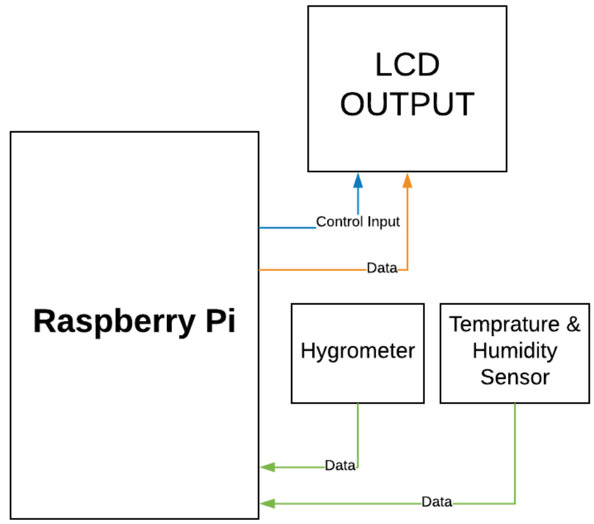

Fig 1. Data Flow in the IoT Device

The hygrometer and the humidity-temperature sensor sends the data to the Raspberry Pi, which is connected to an LCD device for output. The Raspberry Pi computes the results based on the fetched data and displays the output on the LCD screen. The circuit diagram of the proposed IoT device is depicted in Fig 2.

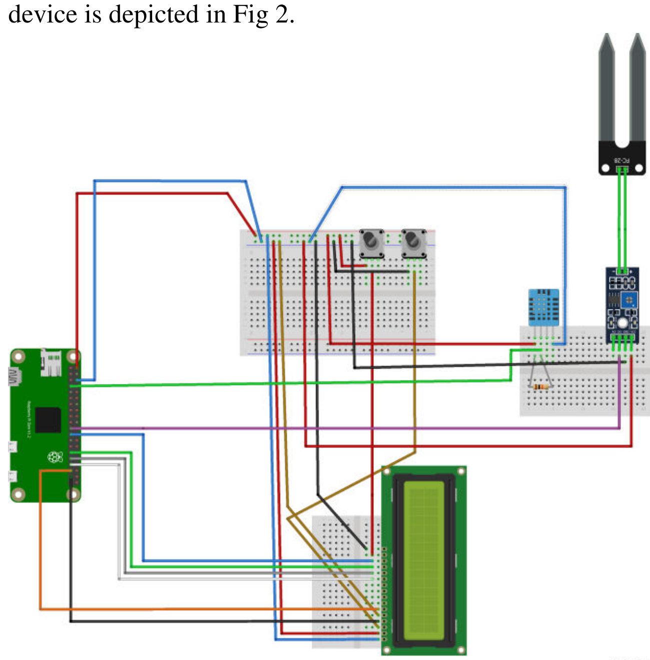

Fig 2. Proposed Design of the IoT Device

The collected data is fed to the machine learning model which traces the relationship between the values of ERH and EMC for various grains on different temperatures. It is observed over the years that the adsorption isotherms between relative humidity and moisture content have the usual sigmoid shape [15]. We used this very knowledge about the relationship between the two and plotted the data

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in table 1 to witness that the data fits the model accurately and can be used for calculations once tuned. Fig. 3 displays the exact data traced for the values of rice at temperatures 35, 50, 75 and 100 F from table 1, fig. 4 elaborates on how the given data fits the sigmoid model, for different temperatures, and fig. 5 is the final model which is used for further analysis. It is tuned to minimize errors for exact results.

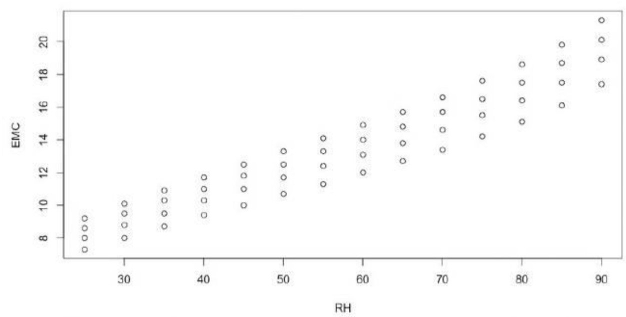

Fig 3. Rh vs EMC for Rice at temperatures 35, 50, 75, and 100 F.

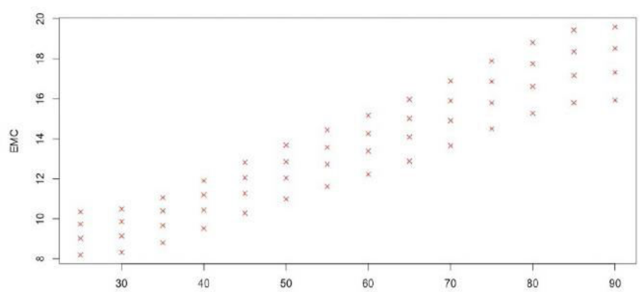

Fig 4. Tracing the data for rice from table 1 against a sigmoid function to generate a functioning model.

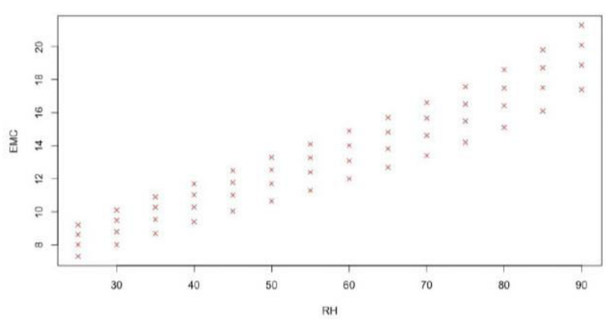

Fig 5. Tuned model used for alert generation and data monitoring.

Fig. 6 Gives a detailed description of the proposed model and its flow of control. The following steps are followed by our IoT device and the related model.

1. Data Collection: The IoT uses Hygrometers and Temperature sensors to collect the data from the storage unit.
2. EMC Calculation: The data is then fed into a trained ML model which is designed to estimate the value of EMC for the specific grain at the current environmental conditions.
3. Threshold Verification: The EMC value is then compared to the observed threshold values past which the grains are most likely to decay.
4. Output Generation: If the EMC value is beyond the threshold value, an alert is generated with an estimation of grain decay timeline. If the EMC value is below the threshold, the device progresses to step 5.
5. Halt and Proceed: In order to manage its workload, the device halts for a few minutes post every calculation and restarts after the fixed interval as temperature and humidity do not vary constantly and a slight delay will not affect the outputs of the system.

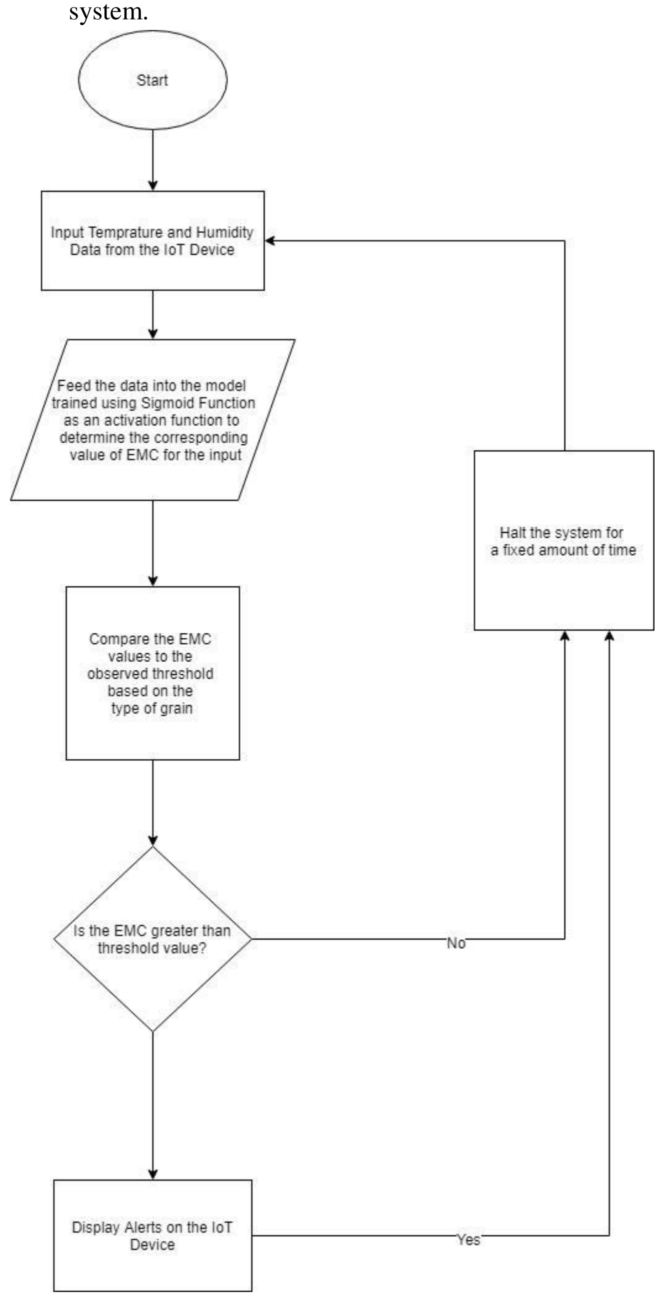

Fig 6. Flow Chart depicting the flow of control within the IoT device

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Results

It was observed that wheat can be stored for 16-24 hours without degradation at an EMC level between 12-17% whereas, rice can be stored for 30-40 hours without degrading at an EMC level of about 24% but if the rice isn't mature yet, raising moisture above 15% can lead to fissure and hence degrade the grain quality. So, a moisture level below 15% can be assumed fit for long term storage of rice grains whereas a temperature below 12% needs to be maintained for storage of wheat, making these are thresholds for alert generation. Our studies show that there is no microbe growth if the water activity is below .75, even if the EMC levels are high enough. Hence, maintaining a water activity level below .75 is a must. Alerts are generated if the EMC levels exceed the threshold or water activity crosses this .75 mark.

A classification model works in coordination with the output of the above described regression model to classify grains as *Danger* or *No Grain Danger*. This result is sent as a response to the request made by the IoT device.

Conclusions

The degradation of grains can be directly linked to water activity (a_w) of the grains. An increase in water activity promotes the production of ethanol, carbon-di-oxide and other volatile microbial metabolite content which leads to growth of microbes if left untreated. Degradation of most cereal grains begins at a water activity (a_w) greater than .75 hence, this can be used as a threshold for alert generation. The moisture content at which degradation begins varies from grain to grain. For wheat, the grains begin to degrade within 16-24 hours once the moisture content reaches to about 12-17%. For rice however, the degradation begins at a much greater moisture content i.e. degradation begins within 16 hours once the moisture content reaches above 25%.

The proposed IoT device, collects temperature and humidity statistics from different parts of the warehouse throughout the day. For every individual reading, the Equilibrium Moisture Content (EMC) is calculated using the trained and tuned model. Both water activity and moisture levels are taken into consideration. The moisture or water activity levels, when beyond safe regions, trigger a time-bound alert on the system. Once the alert is triggered, the grains must be dried to reduce the mycotoxin levels and other responsible conditions should be treated within this amount of time or else it would be impossible to avoid further decay. If the conditions are not treatable it is advised to dry and dispatch the grains as soon as possible.

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