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Digital twin approach for post-harvest crop protection

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Abstract

This technical paper presents the Internet-of-Things (IoT) and cloud platform solution for post-harvest crop protection. Centaur Internet-of-Crops® (IoC) is an AI-based cloud platform that processes a wide variety of data coming from proprietary and 3rd party sensors (Temperature, Rel. Humidity, CO2, O2, Fumigant concentrations, Product quantity, NIR spectrometry data, Weather data) into predictive and prescriptive digital twins, for sustainable agri-food supply chains and farm-to-fork traceability. The wireless sensor solution has been conceived to work in demanding rural and industrial environments. Centaur IoC® uses Computational Fluid Dynamics (CFD), to create a digital twin (simulation-augmented model) and applies machine learning to predict quality related problems in stored crops and containerized or bulk shipments. Fusing IoT devices with digital twins and analytics allows to protect a large mass of food/agriproducts with a modest number of sensor devices, precisely determine the quantity of stored products, and uniquely identify the provenance and identity of a stored crop.

1. Introduction

One third (~1.2 billion tons) of food produced is lost or wasted annually. Lack of real-time data across the supply chain affects agri-food products, impacting all below segments with chronic post-harvest waste problems: on-farm storage, county, port and export elevator, ingredient processor, transportation and food & beverage company. Users demand to increase sustainability, predict spoilage events, avoid insect damage, implement precision fumigation, track transported product quality in real time, identify grain fingerprints for traceability, mitigate losses, and secure price premiums.

Centaur has implemented the Internet-of-Crops® to provide the asset managers with a digital twin of their assets. So, they can monitor and interfere with and keep the product in a good state for a long-term. The architecture of the Internet-of-Crops® consists of 2 main parts: a) the On-site system b) the cloud infrastructure. The on-site system is installed at the location of the asset and consists of the devices which are in the IoC® while the cloud infrastructure includes the User Interface, and the Analytics. The conditions of the asset are collected from the sensors in the on-site system and measurements are consumed from the Analytics service on the cloud. To help the user keep the product in good condition, the IoC® interferes with the asset mechanisms by enabling or disabling actuators and alarms.

2. Sensor Technology

A Wireless Sensor Network (WSN) is installed in each asset to collect its conditions. The WSN consists of the gateway and the sensors. The nodes communicate with each other, using a proprietary protocol based on the IEEE 802.15.4 technical standard. The sensor data travels from the devices to the gateway synchronously using a duty-cycle based operation. There, after a first-level evaluation, the data are transmitted to the Internet-of-Crops® online platform. To extend the coverage to large areas, a special type of device can be used to act as a repeater. This device, that can be solar powered, will increase the range of the WSN, while making it more reliable and robust.

The sensor devices are placed inside facilities for an extended period of time, covered by the product. This provides the need to reduce power consumption in order to extend the battery life as the devices become inaccessible during the whole season. Power optimizations along with the duty cycle operation, give us the ability to extend the battery life. This scheme divides the operation into three states, a short-time wake state, a short-time sampling state and a long-time sleep state. During the wake state, the radio is turned ON and any node in the network will communicate with each other. In the sampling state, the hardware will become enabled in order to retrieve the measurements. Throughout the sleep state, all the devices are in a low power mode, keeping most of the hardware components in a powered-off state. The duration of the sleep period is determined by the user and may be different depending on the needs of each asset.

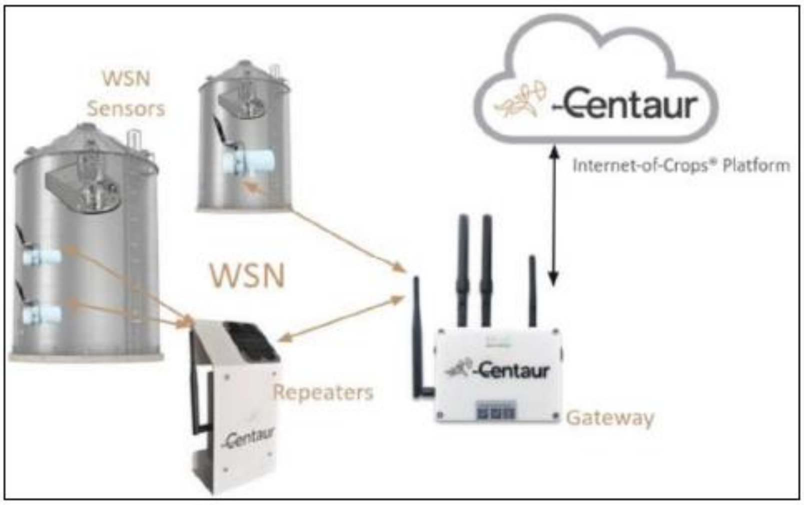

Figure 1: On-site system architecture diagram.

Centaur's online platform receives sensor measurements such as Temperature, Rel. Humidity, CO2, O2, Fumigant concentrations, Product quantity, NIR spectrometry data, and Weather data. These measurements are direct or indirect indicators of product quality conditions. Through smart AI inhouse algorithms, platform users can monitor their product quality state, extract valuable information about safe storage time range, insects and microbial communities creation, specific grain quality estimators (e.g germination capacity for barley) and aeration schedule recommendations to improve storage conditions.

3. Digital Twin Technology

Except of the monitoring information, Centaur creates a digital twin model per storage facility in order to predict the evolvement of grain quality parameters along with time. Using Computational Fluid Dynamics (CFD), the model is able to simulate the thermodynamic properties of grain and air inside the storage facility, taking into account outside weather variations, aeration events when fans are turned on and fumigation campaigns when fumigant gases are supplied into the storage facility.

Sensor measurements are used to update the model with the latest storage conditions. Through the CFD model, sensor pointwise information is translated into full grain volume information, since the model calculates the quality parameters along the full facility geometry.

Model predictions are used as decision points for platform users since they can plan in advance their next steps regarding grain storage time, fumigation plans, grain quality and price.

The simulation domain is formed based on the real storage facility geometry. For the CFD model, Centaur uses the opensource OpenFOAM package. Three different zones and their physical, thermodynamical and electrical properties are defined as: Grain, Air, Wall.

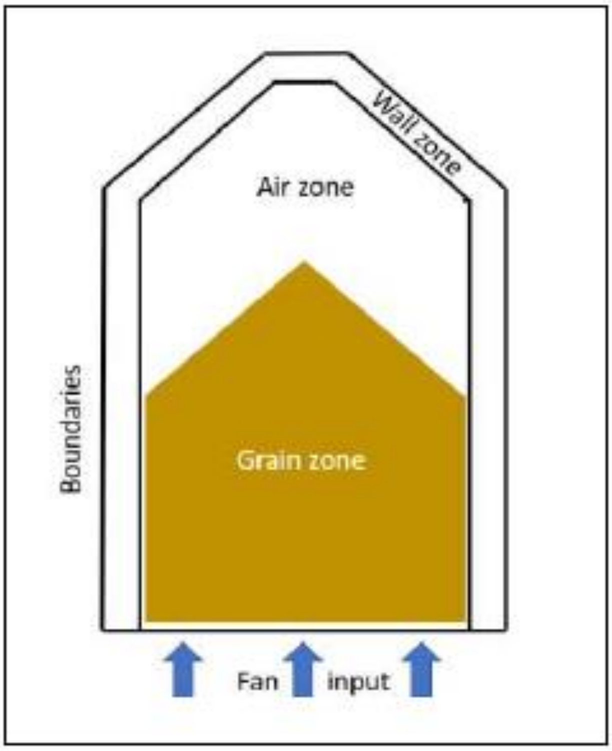

Figure 2: 2-D representation of a silo simulation domain.

Zones are modeled as porous materials and especially for the grain zone, grain respiration activity is introduced as a heat and CO2 source.

Computational mesh generation is parametric based on facility geometry and is produced with respect to the mesh quality indicators such as orthogonality and skewness. Optimal mesh sizes are applied per grain volume after mesh independence studies.

Initial conditions are applied on the zones, translating sensor measurements into the grain volume. Grain Temperature and Moisture Content are the minimum required inputs.

Boundary conditions are based on hourly weather data and aeration properties if the fan is turned on and they are applied on the simulation domain boundaries.

Finally, a transient simulation is triggered with adaptive time step. Simulation results are available online on the Internet-of-Crops® platform in the form of daily quality condition contours.

After a 360 days validation process, real time sensor measurements and CFD model predictions are compared to justify model accuracy.

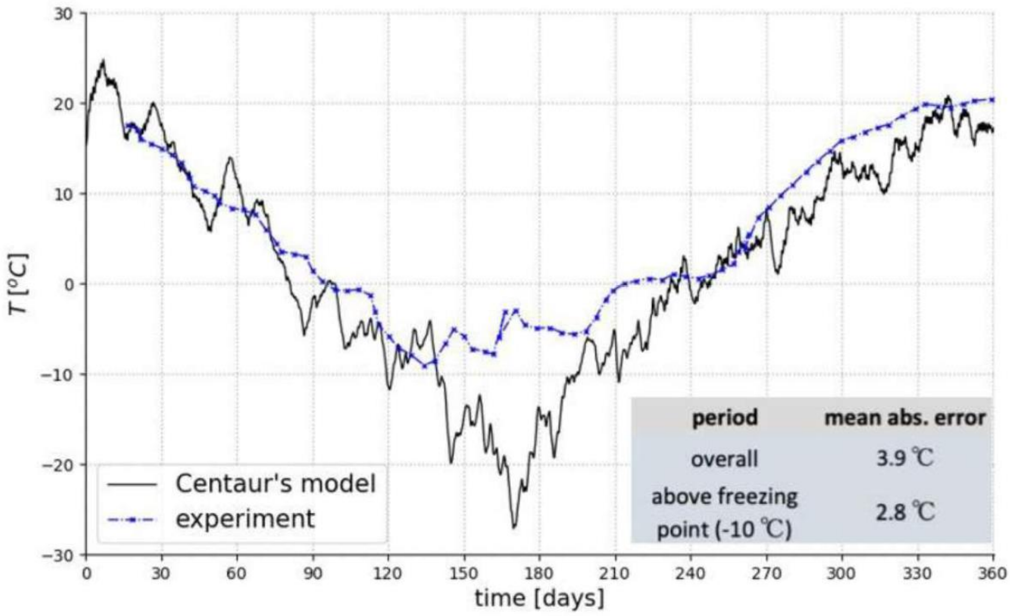

Figure 3: Temperature comparison between model and measured values.