Digital twin for prediction of cold storage conditions of fruit by real-time sensor monitoring

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Optimal storage of fruits requires more than temperature control. Our work targets the remote monitoring and prediction of condensation on the apple surface. In order to fully understand the spatial distribution of storage conditions, several in-house developed sensors were applied, including dewpoint difference based on commercial humidity sensors, a hotwire anemometer to measure airspeed in the cavities between the fruit, heat flux on the fruit surface, and fruit surface wetness. The measurements from the dewpoint difference and the wetness sensors were transmitted wirelessly by LoRaWAN (Long Range Wide Area Network). The other sensors were equipped with a USB interface, connected to multiple Raspberry Pi embedded controllers, which acted as an Ethernet gateway. The system goes beyond Internet-of-Things (IOT) by combining the remote sensor data with complex modelling in real-time. The Digital Twin platform enables flexible linking of any sensor with any model. Models can run in multiple instances, e.g., to predict condensation in different bins in the storage room. All sensor data and model predictions are collected on the Kafka streaming platform. The Software is organized into services to copy sensor data from remote gateways, apply calibration values, resample sensor data to compensate for deviating sampling intervals, and model implementations. Several services can be linked in a chain through the streaming platform to provide complex sensor data processing. The sensor capacity of our Digital Twin is highly scalable. The measurements from 100 sensors, placed in two 40-ton cold storage rooms with apples, could be handled after installing additional Ethernet gateways and a second LoraWAN gateway. The Kafka broker and all services were executed in real time on the same server without creating computation bottlenecks. The InfluxDB database was applied as a web-based graphical frontend. This contribution presents the fruit-specific sensors, the Digital Twin platform and results from field tests.