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

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Goal: Optimizing fruit storage conditions

- Digital Twin for real-time 'live' monitoring and control
- Humidity / dew point undershoot as crucial influence
- Modelling of condensation status



Verify model prediction of condensation by measurement with weighing scale (single and bulk apples)

Sensor system

- Combining wired (USB) and wireless (Lora) sensors
- µController provides I²C + analog inputs
- Raspberry Pi forwards USB via Ethernet to data base



Custom made board to include project specific sensors



- Relation of humidity –condensation – weight loss – fungi growth
- Direct measurement of condensation in practical application hardly feasible \rightarrow Modelling



Test of remote live monitoring standard bin (300 kg) Cold storage room (40 t)

Actual Apple Mass

Digital Twin streaming platform Link any sensor to any model Implemented as Based on Kafka / Linux / InfluxDB, Python, TSL Encryption Services Performance: More than 50 sensors + models can run on virtual machine with 4 cores Data organized in topics, e.g.: apples.20250317.kob314.sensors.wet45a **Linux Cloud Server** Display / Combine Condensation Lora Resampling Export -Lora/ TTN InfluxDB Sensors Model Import Server Kafka Streaming Platform LoRa Sensor





Realtime monitoring of temperature and dew point

- Compare dew point and apple surface temperature
- Identify different types of condensation triggers
 - Door opening, set point change, defrosting, loading of 'warm' bins,
 - Cooling interruption (Screenshot)



Spatial distribution of temperature / dew point

- Measurement in cold storage room with 40 t of apples (3 rows with ~ 50 bins each)
- Two sensors on flexible board to measure temperature difference and calculate dew point

Surface temperature deviations

- Variation > 0.7°C after 5 days of storage (different loading time / precooling)
- Relative to average value 2.143°C





Dew point undershoots

High likelihood of condensation, if surface temperate < dew point (blue)



For further publications on digital twins, condensation and fruit monitoring, see www.intelligentcontainer.com

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