Wireless Sensors for Quality Monitoring and Management of Stored Grain

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Introduction

The most used automated stored grain bulk monitoring technology relies on temperature and moisture sensors incorporated into steel cables suspended from the roof to the floor of bins. However, cable-based sensors can be expensive and require reinforcing roofs to account for the frictional forces exerted by the grain mass on the cables during loading, settling, and unloading. This report discusses wireless sensors as an alternative. These three studies took place in storage bins at the ISU Ag Engineering/Agronomy Farm, Boone, Iowa.

Study 1

Methods. The objective was to determine the effectiveness of wireless sensors versus cable sensors by monitoring temperature and relative humidity (RH) in the interstitial air of the stored grain mass. A 32-ft diameter stir-drying bin was loaded with approximately 8,000 bushels of corn. Six cables with built-in digital sensors together with 15 Amber Ag wireless sensors fastened to the cable sensors were probed into the grain mass. Temperature and RH data were collected from the cable and wireless sensors three times a day.

A hand-held high-accuracy temperature and RH meter was intermittently probed into the grain mass next to the paired cable and wireless sensor locations for a period of 24 hours at a time to check accuracy of the cable and wireless sensors. Nighttime grain aeration and data collection preceded probing.

The EMC values of both sensor types were determined using the Modified Henderson equation. The Rank-Sum Test statistical analysis compared the temperature and RH values of the wireless versus cable sensors.

Biweekly grain moisture content of samples pulled from the grain mass at the locations of 18 cable and wireless sensors was determined with a calibrated GAC 2500 meter for comparison.

Results. Paired wireless and cable-based sensors recorded similar temperature 85 percent of the time, but RH (and therefore the calculated equilibrium moisture content) only 78 percent of the time during non-aerated storage periods. The results documented that the wireless and cable-based sensors indicated the same temperature and RH as the high-accuracy sensor only 25 percent of the time during aerated storage. However, cable-based sensors indicated similar moisture content 100 percent of the time as the calibrated GAC 2500 moisture meter.

Study 2

Methods. To determine the distribution of brick and spherical shaped wireless sensors as a function of gravity-filling a storage bin and their recovery from the grain mass during unloading. A swing away screw conveyor rated at up to 6,600 bushels per hour (bph) filled a 24-ft diameter storage bin with corn to a grain depth of 16 ft. Wireless sensor shapes (brick vs. spherical), grain flow rates (1,062 bph vs.1,500 bph), and drop heights (17.4 ft vs. 12.9 ft) were the independent variables. Varying the tractor PTO achieved the desired grain flow rates. Drop height was the distance measured between the outlet of the screw conveyor through the center fill hole at the peak of the bin roof and the peak of the grain pile below. Five brick shaped (2 in. length, 0.8 in. thickness) and five spherical shaped wireless sensors—small (diameter 1.4 in.) and medium (diameter 2.6 in.)—sizes were placed in the inlet grain stream of the screw conveyor one at a time in short succession during the last two minutes of fill time so the drop height was approximately the same for all sensors. The distance of each sensor location to the peak of the grain mass along the inclined grain surface was measured after turning off the screw conveyor. The bin was unloaded and the procedure repeated at higher flow rates with filling time adjusted.

For the wireless sensor recovery, 36 first-generation (2 in. long, 0.8 in. wide, 0.8 in. thick) and 8 second-generation (2 in. long and wide, 0.8 in. thick) sensors from Amber Agriculture were dropped into the grain mass during transfer from wagons to the inclined screw conveyor. The sensors were placed in different layers of the grain mass inside the stir-drying silo and came to rest within 3 ft of the bin sidewall when being flung by the electrically powered grain spreader.

A recapture screen between the bin underfloor unload screw conveyor and the inlet of the inclined belt transfer conveyor collected sensors at ground level during unloading of the bin. This experiment was repeated three times with 15, 20, and 25 brick-shaped wireless sensors placed in the grain mass. One-time 15 medium-size spherical-shaped wireless sensors also were placed in the grain mass and unloaded.

Results. The spherical-shaped wireless sensors rolled 3.3 times further along the slope of the grain surface than brick-shaped wireless sensors. Higher gravity filling rates caused both shapes of sensors to come to rest closer to the center peak than at lower grain flow rates. Rolling distance along the sloped grain surface of spherical shaped sensors may be varied based on diameter and weight. As a result of this study, having a mix of both spherical and brick sensor shapes could be used to achieve a representative wireless sensor distribution within a stored grain mass as a function of gravity filling of a grain storage bin.

Spherical- and brick-shaped wireless sensors were successfully recaptured during unloading of bins with 100 percent recovery rate. However, 7 out of 44 brick-shaped sensors (16%) were damaged during unloading. Damage to the wireless sensors during unloading would prevent their use as part of an effective stored grain monitoring system.

Study 3

Methods. Verification of the accuracy of the 3D MLP-FE ecosystem model in terms of temperature prediction in a stored grain mass during aerated periods. After in-bin stir drying, six temperature and RH cables were probed into the 9,000 bushel grain mass with continuous aeration for a period of two weeks (04/10/2019 to 04/25/2019). The measured airflow rate of 1.4 cfm/bushel resulted in an air velocity of 0.215 m/s at a static pressure drop of 2.7 in. assuming 40 percent porosity. The grain mass had 18 cable sensors at three grain depths (4.3, 8.2, and 12.1 ft) with six sensors per layer, respectively. Observed hourly temperature and RH cable sensor data was compared with the predicted values of a 3D aeration and drying simulation model.

Results. The observed and predicted temperatures were in close agreement with a standard error of prediction ranging from 36 to 39°F and average of 37.6°F. The results verified the accuracy of the 3D simulation model to predict stored grain temperatures as a result of aeration. The accuracy of the temperature prediction was better at the center of the grain mass than in the periphery where the effects of varying ambient conditions and especially solar radiation are the greatest. Similarly, temperature prediction was better at a distance close to the perforated plenum floor, especially during aerated periods, due to exposure to the ambient air temperature from the high-airflow fan.

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