Precision Agriculture, 3, 169–182, 2002

A Review of Combine Sensors for Precision Farming

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Abstract. To maximize economic return from agricultural production units, costs have to be minimized and benefits maximized. For grain, kernel yield and quality have to be maximized while the use of seeds, fertilizer, herbicides and fungicides have to be optimized.

The best location to evaluate productivity levels, by measuring yield and quality of grain and straw, is the combine harvester. Moreover, other grain quality characteristics like density or test weight can be determined for use as an evaluation tool. In this paper, an overview is given of the past and current research toward the evaluation of currently available commercial sensors (e.g., for measuring grain yield and grain moisture content) as well as toward the development of new sensors (e.g., grain protein content and straw yield).

Keywords: combine, sensors, grain yield, grain quality

Introduction

One of the most important objectives of farmers is the optimization of profit for each field. One approach is to minimize inputs. This benefit is directly correlated to yield and crop quality. For a long time, this improvement has been obtained through a thorough crop selection for specific climates, and for an increased resistance to pest infections. Better fertility management supported these improvements. Higher yields are sometimes accompanied by an increased leaching of pollutants to the environment. Misapplication of fertilizers and pesticides results in pollution and increased pressure on the environment. Farmers are under increasing legislative pressure to reduce fertilizer, pesticide and herbicide inputs.

Precision farming is likely to provide a solution for these problems. During the growing season, one can visually detect differences in a field. Different growing conditions result in varying grain yield, weed infestation etc. Fertilizer and herbicide application can be adapted to this variation in a site-specific manner to obtain maximum economic yield. To evaluate this profit, yield has to be determined site-specifically. With cereal grains, the only place to measure the latter is the combine harvester. So within precision farming, combine harvesters play an important function.

About 15 years ago, research was initiated toward the site-specific measurement of grain yield. The first commercial sensors appeared five years ago. Nowadays, research is focused upon the measurement of grain quality and yield of other crops (sugar beets, forages, potatoes,. . .), but also on the comparison and evaluation of existing technologies.

The following paper is meant to be a guideline through the research on different commercial sensors available, new developments that can be expected with respect to these sensors, and research toward new sensors which will provide the farmer additional information. It is important to know that each sensor has its limitation, especially with respect to its limited accuracy, which can vary according to different field conditions. The following paragraphs pay special attention toward the described accuracies and disturbing factors. However the reader should be careful because not every author is interpreting the observed accuracy of these sensors in the same way.

Current technologies

Research on sensor technology for precision farming continues to escalate. Research involves the measurement of flow rate as well as different properties of grain and biomass. The placement of these sensors on the combine can be easily understood when looking at the different functions of the harvester. Components of a conventional combine are shown in Figure 1. At the combine header, the crop is cut and fed to the threshing mechanism. Here grain is loosened from the crop. Subsequently, grain and straw are separated. In a last step the grain is cleaned to remove foreign matter and chaff. After cleaning, the grain is transferred to the grain bin with the aid of augers and elevators. Measurements on clean grain, like volumetric or mass flow, can only be done at this last stage. When the crop is cut low enough to the ground, measurements on the straw can be executed on nearly every place in the combine where straw is passing through, even when mixed with grain. The fraction of grain is rather low in weight and volume compared to the straw fraction. Measurements on field properties of the crop, like plant population or lodging losses of the grain crop, has to be performed in front of the header.

Grain yield meters

Kutzbach and Schneider (1997) and Hindryckx and Missotten (1994) give overview of the different measurement devices for the measuring of grain yield (Figure 2).

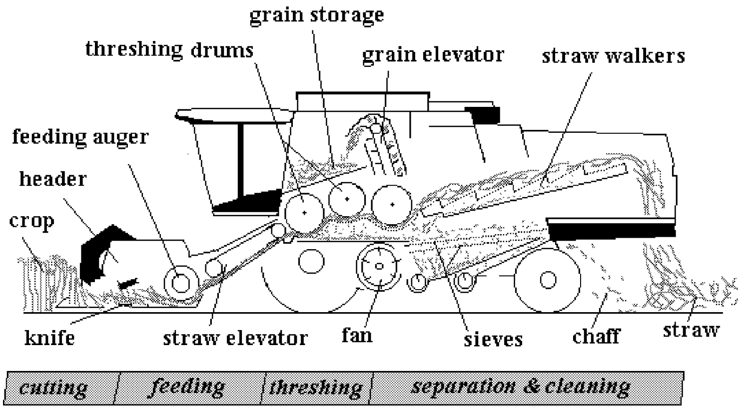

Figure 1. Different functional processes in a conventional combine (Missotten, 1998).

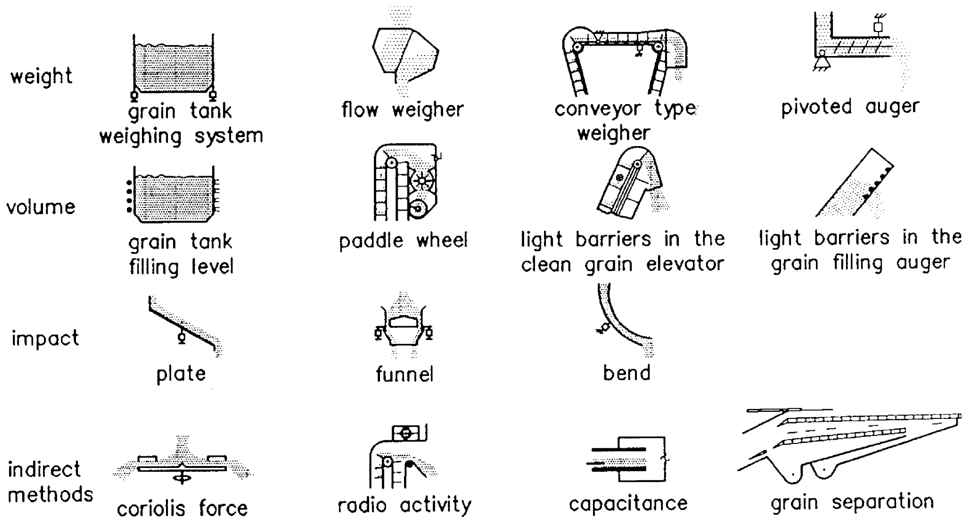

Figure 2. Different methods for the measurement of grain yield (Kützbach and Schneider, 1997).

Mass or volumetric flow sensors can be divided in four groups, depending on the principle of measurement. When evaluating these sensors, different critical points have to be considered:

- ease of calibration, preferably independent of crop type;
- sufficient precision and accuracy;
- no obstruction of the normal threshing process, even when the sensor is damaged;
- ease of mounting on different combine types and models.

Below, a more detailed overview is given of published research on different sensors as well as an overview of commercial sensors available on the market. Advantages and drawbacks are discussed:

Mass flow measurements. The basic principle of these measurements is the combination of a weight and speed measurement. Frequently the grain mass is measured by weighing machine components that transport grain. In general, problems are noted with dependence on the moisture content and combine operation on slopes. Moreover, these measuring devices are difficult to construct.

Some examples:

- Weighing of the grain bin (Colvin, 1990). Mass flow equals the change of weight of the bin in time. As the grain bin has to be mechanically isolated from the harvester, the construction of the sensor is not easy. The author noticed problems when measuring on slopes. Moreover, accuracy is limited because the weighing cells have to be adapted for the weight of a full grain bin.
- Weighing of pivoted auger (Wagner and Schrock, 1987).
- Weighing of an element at the bottom cross auger (TSI Montana). The grain is measured as it travels through the bottom cross auger before it reaches the clean grain

elevator. The manufacturer claims independence of crop type. The advantage of this system is the lower time delay, as the system measures at the first point where the grain is cleaned.

- Weighing of an elevator (Schrock *et al.*, 1995). The conventional elevator, transporting the clean grain to the grain bin, is replaced by a triangular construction. The upper part is pivoted at one side, and mounted on a load cell at the other side. The signal of this load cell together with the speed of the elevator sprocket wheel is used to predict the mass flow. The linear relationship with grain yield is dependent on cereal variety and moisture content. When an overall regression line was calculated, the maximal error at validation was 5% at a measured weight of 2097 kg. However, this validation occurred on the same day and the same field as the calibration. As a combine is normally equipped with a linear elevator, it needs a strong modification to install this sensor.

Volume flow measurements. Volume of grain is measured when flowing through the sensor during a fixed time interval, or time is measured needed by a fixed volume of grain to flow through the sensor. To convert this volume flow into mass flow, mass density has to be known. The mass density depends on grain variety and growing conditions. To acquire accurate measurements, mass density has to be measured for each different field, or even different measurements on one field.

Optically. By means of optic sensors (light emitter and detector), height of the grain on the elevator paddles is measured. By aid of the registered height, the total volume of grain on the paddles is estimated. Combined with elevator speed, the volume flow is derived. Together with the conversion of volume to mass, the conversion of height to volume is a second drawback of this sensor. The volume of grain with respect to height is not always the same for the following reasons:

- altering shape of the grain mass on the paddle with changing slope of the elevator, both in the driving direction and perpendicular to it;
- changing grain mass shape with changing friction properties of the grain (depending on moisture content, variety, …);
- asymmetric feeding of the elevator by the auger.

This sensor has been studied in different forms, depending on the configuration of the light emitter(s) and detector(s). One possibility (Diekhans, 1985) is to place the emitter and detector aside from the elevator.

This one-dimensional system has been studied by Strubbe *et al.* (1996). When tested at a transverse slope of 11%, the difference between estimated and real volume approached 13% at high flow rates. By using a two-dimensional system, placing two sensors at each side of the elevator, the results could be improved. To estimate the volume, a model was developed by applying the stepwise multiple linear regression method to measured data. Maximum error was 9% at the maximum slope. To improve further these results, the grain should be spread more homogeneously on the paddles. By vibrating the machine, the grain surface is more flattened near the top of the elevator, but placement of the sensor is more difficult. Also, a better resolution of the emitter-detector system could improve the results.

Reitz and Kutzbach (1992) describe a two-dimensional system with one emitter/detector pair aside of the elevator, and two at the backside parallel to the driving direction. By introducing the latter pair of sensors, the accuracy when harvesting on a hillside could be strongly improved.

Hummel *et al.* (1995) tested a similar sensor developed by Pfeiffer *et al.* (1993). Light emitted at one side of the elevator is captured at the other side by 4 photodiodes. When the calculated calibration model was validated on a different field, the error was maximal 4.5% on a reference weight of 160 kg. The calibration curve was non-linear, and this deviation from linearity increased with moisture content. Pfeiffer noticed an increased error caused by irregular running of the engine when loading of the threshing mechanism varies. The influence of varying slope was not discussed.

Paddle wheel. When leaving the elevator, grain is thrown into one of the cells of a paddle wheel. When the cell is filled, the wheel turns and the following cell is filled. The volume of the cells is known, and when the number of revolutions of the wheel is known the volume flow can be calculated. This sensor is called the Claydon Yield-o-meter, according to the inventor. Major problems are the discrete measurement (the wheel is not turning continuously), and the possible obstruction of the machine when the sensor is damaged. For example when the wheel jammed, the grain flow through the elevator is blocked as well, possibly resulting in damage to the elevator as well.

Searchy *et al.* (1989) used the sensor to create a yield map, which resulted in an error of 7.1% on total yield for a 1.3 ha field.

Birrell *et al.* (1994) compared the Claydon sensor with an impact-based sensor, when used for yield mapping. The error on the total yield of a field was similar, but when looking more in detail on smaller surfaces, the signal of the Claydon sensor contained more noise. This was attributed to the discrete measurement method of the sensor. Unfortunately, the authors didn't publish any statistics about the accuracy of this device. The manufacturer of the sensor claims an accuracy of ±1% once the moisture content and density are determined correctly (Murphy *et al.*, 1994).

Stott *et al.* (1993) found an error of ±10% when volumetric flow was compared to weighing the contents of the grain bin.

Impact sensors. Most commercial sensors rely on impact sensing for mass-flow measurement. In these sensors the impact force or moment, caused by the change in momentum of the grain flow, is measured. The plate can be flat or curved, or just a pair of fingers. These sensing devices are mounted at the top of the elevator.

Vansichen and De Baerdemaeker (1991) developed an impact-type yield sensor with a curved plate. When tested in the lab, an error of 1 to 2% was noticed. However, the maximum error in the field was up to 3.5%. The calibration of the sensor was influenced by the slope of the field and was dependent on material properties like moisture content, friction, and kernel size. Strubbe (1997) reduced this material dependency by changing the mounting of the plate based on measured moments at a specific angle. Moreover, the signal to noise-level was substantially reduced. This improved system produced a maximum error of 5% under all field conditions, independent of crop variety and moisture content. The calibration curve was linear, and had only to be determined once a season. When predicted values with this calibration are compared with the mass, measured with a load cell, the error is less than 0.5% under normal harvesting conditions. Arslan and

Colvin (1998) tested the AgLeader 2000 yield monitor in a laboratory test stand. When the flow rate was kept constant during each test run, a correlation coefficient of 0.99 was achieved, where the largest difference was 9.17%. However, varying the flow rate during the test run seemed to cause the sensor to be less accurate. Also minimum test run duration and flow rates (1.5 kg/s) were required to achieve this accuracy.

Indirect methods

Radiometric. At the end of the clean grain elevator, the grain flow is exposed to the γ-rays of a radiation source. At the opposite side of the grain flow, a detector measures the magnitude of the transmitted radiation. Absorption of the radiation is proportional to the mass flow. The signal is mostly independent of grain type or moisture content. In spite of its small size, the radiation source poses a potential risk to users. If the sensor is separately calibrated for each grain type, errors are limited to 2%.

Capacitive. The change of the dielectric properties of the material between two capacitor plates is measured (Stafford *et al.*, 1991). The dielectric constant of the mixture of air and grain increases as the mass flow increases. However, the dielectric constant is not only dependent of the mass flow, but also of the moisture content and grain type. Separate calibrations must be executed for each grain type. The calibration curve is non-linear and partly dependent of the moisture content.

Comparison of different measuring principles. Kormann *et al.* (1998) compared different grain flow sensors, and summarized calibration errors of the various sensors used in several years of field tests. The error for the Claydon Yield-o-meter (with paddle wheel—commercialized by the Claas company) varied between 6.40 and −8.48% at a 95% confidence interval. A significant portion of this error was caused by variation in mass density of the grain. A second volumetric sensor, the RDS Ceres II system, had a similar error, ranging between −7.02 and 6.85%. The grain moisture content is a significant disturbance parameter. The range of the Massey Ferguson radiometric sensor was from −9.15% to 7.15%, and for the AgLeader yield monitor −10.11% to 5.67%.

In 1997 Kornmann *et al.* conducted laboratory tests with wheat (14% moisture content). Again four sensors were tested, but the Claydon (Claas-) Yield-o-meter was replaced by the Claas Quantimeter 2, an optical sensing system similar to the RDS sensor. In the first test, the error was measured at different mass flows. Five replications were made at each mass flow. The overall error range at a 95% confidence interval for the RDS Ceres 2 sensor was 0% to 2% and −1.5% to 2.5% for the Claas quantimeter. The error was greater for the radiometric sensor and the AgLeader 2000 yield monitor, respectively (−3%, 1.5%) and (−4%, 2%). With those two sensors, the error increased significantly at low flow rates.

The slope of the field was less of a factor using the Massey Ferguson radiometric sensor (total error between −2.5% and 0.5% at 95% confidence interval). For the AgLeader 2000, the Quantimeter II and the Ceres 2 sensor the error ranges were (−4.5% to −1.5%), (−5.2% to 3.2%) and (−3% to 9.2%) respectively. The two volumetric sensors are clearly influenced by the slope.

Overview of commercial systems. RDS Technology Ltd[1] produces a yield mapping system (Ceres) based on volumetric measurement. An emitter/ detector system is mounted on the side wall of the clean grain elevator. This system was patented earlier (1982) by the Claas company.

The Claas[2] quantimeter II is similar to the RDS sensor.

The Greenstar™ yield mapping system of the John Deere Company[3] uses an impact style mass flow sensor with a curved plate. The deflection of the plate is measured via a linear potentiometer.

Case IH[4] (Advanced Farming Systems AFS™) utilises the impact sensor developed by AgLeader™.[5] This impact-type sensor has a flat plate on which the deflection is measured by aid of strain gauges. The Deutz-Fahr Teris[6] system uses the same sensor.

The GRAIN-TRAK yield measuring system by MICRO-TRAK[7] uses two fingers to measure the impact force.

With the Fieldstar® precision farming system of Massey Ferguson (AGCO[8]) a radiometric yield meter is used. However, in countries where the use of the radioactive radiation source is not allowed, an impact system with two measuring fingers is purchased.

Harvest Master[9] registers grain flow by measuring the tension in the elevator chain. The iddler wheel support is replaced with a load cell to measure the chain tension.

Straw yield measuring system

Various studies have been conducted regarding straw yield measurements on a combine harvester. In most cases, the sensor was not studied for application within precision farming practices, rather the intended application is the speed control of the combine. As straw flow significantly influences machine loading, the sensor may be an important tool for increasing harvest efficiency.

An overview of previous work is presented according to the measurement location on the machine:

At the combine header. Schueller *et al.* (1982) tried to measure the driving force exercised on the header cross auger to move the straw to the feeder housing. No correlation was found between straw flow and tension in the drive chain. Possible causes included low sensitivity of the sensor, friction and uneven residence times in the auger. Low sensitivity was necessary to maintain shock strength.

Huisman (1982) describes a sensor for measuring the tension on the driving chain of the header cross auger. Although a rather good relation was found, specific problems with the sensor construction were reported.

In the feeder house. The feeder house transports straw to the threshing cylinder by aid of paddles on a chain. The shaft of the elevator chain at the header can move up and down and is restricted by a spring. At high straw flow rates, the spring will be compressed and a thick straw mat will be formed under the chain. Nakhamkin and Mikhailov (1960) and Famili (1983) measured the length of the spring to predict straw flow. Famili (1983) also tested two other sensors in the feeder housing. The first one measured the pressure, executed by the straw on the bottom of the feeder housing. A second sensor measured the driving tension of the elevator on the shaft. Both sensors had a low accuracy, and the first sensor was sensitive to stones. Schueller *et al.* (1982) measured the torque of the feeder chain drive motor. Within one day of measurements, a good correlation was found with the mass flow (correlation coefficient of 0.99). However, when an overall calibration was calculated for various crops, fields and times, the correlation coefficient dropped to 0.79. This illustrated the sensor dependence on crop type and harvest conditions.

Missotten (1998) tested three sensors. Two of them were mounted at the cross auger, the third measured the mat thickness in the feeder housing. At the cross auger, one sensor measured the tension in the drive chain tension by aid of the deflection of a spring, the other one used a pressure sensor. For increased accuracy under all conditions, different springs were required for the first sensor. To avoid this, a second sensor was developed, which has a maximal error of 10% when calibrated with straw weight measurements. The sensor measured the chain tension, executed on an idler wheel mounted on a hydraulic piston. In the oil reservoir, a pressure sensor was mounted. Although the sensor output exhibited a linear relationship, the relationships were unique for each field. The third sensor, designed to measure the mat thickness, was not sensitive enough. To overcome this problem the tension of the spring was reduced. However this reduction caused an irregular material flow to the threshing cylinder.

Material flow at the threshing elements. Eimer (1974) measured the driving force of the threshing cylinder. However, this is greatly dependent on the spacing between threshing cylinder and concave, which can be adjusted by the driver.

Engine speed. Schueller *et al.* (1982) tried to correlate engine speed to straw flow. At high engine speeds, a non-linear relationship was found. By fitting a linear model, a correlation coefficient of 0.71 was achieved.

Other sensors needed for mapping of grain- and straw yield

Both grain- and straw yield is quantified as mass per unit area. To calculate the yield from the signals of straw- and grain flow sensors, additional data are required. These include cutting width and speed.

Cutting width. Vansichen and De Baerdemaeker (1992) tried to measure the distance between crop divider (mounted on the combine header) and the unharvested crop by aid of an ultrasonic sensor. The maximum error was 0.12 cm. Because of the blind zone, the sensor was positioned beside the crop divider which causes the crop to be flattened when entered at the beginning of harvest. This problem was solved by Missotten (1998) by placing the sensor at an angle of 90° and using a deflection plate (Figure 3). Two sensors were placed in this way at each side of the header, with a measurement range of three meters. The measurement error was less then 5% of the unharvested width.

Wild *et al.* (1998) tested three possibilities to measure the cutting width: mechanical, image processing and ultrasonic sensing. The best results were obtained with the ultrasonic sensors, followed by the image processing system and the mechanical device. The mechanical device needed plant contact. As a result, it interfered (in some cases) with the harvesting operation and in addition could potentially be damaged by the crop.

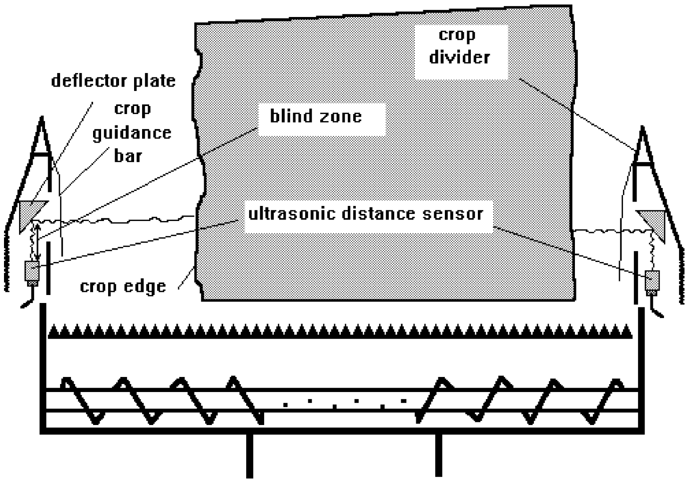

Figure 3. Measurement of cutting width by aid of ultrasonic sensors (Missotten, 1998).

Ground speed. The ground speed is rather simple to measure. On each machine, a speed sensor is mounted to determine wheel speed. Missotten (1998) compared this sensor with a radar doppler sensor. The error of the speed sensor was up to 15%, where the maximal error of the radar sensor was limited to 2.5%. The poor accuracy of the wheel speed sensor may be attributed to wheel slip.

Quality measurement

Because quality influences market price, a knowledge of the within field variation of the protein content can lead toward increased financial return. Unfortunately, many of the quality parameters are measured in a destructive way.

In using wheat for breadmaking as an example, the most important quality parameters are:

- Mass density
- Zeleny: index which represents the ability of the protein to swell up
- Moisture content
- Protein content

Continuous measuring sensors can only be found for the last two parameters.

Mass density. Böttinger (1990) developed a reference system consisting of two leaf springs joined in a U-shape (Figure 4). At the end of one of the beam springs a reference weight is mounted, while at the other end a small box with known volume is placed. Strain gauges are mounted on both springs. When the box is filled with grain, the bending of the corresponding spring is compared to the other one. In this way, the weight of the sample can be determined, and combined with the known volume the mass density too. After measurement, the box is emptied through an opening in the bottom. The sensor

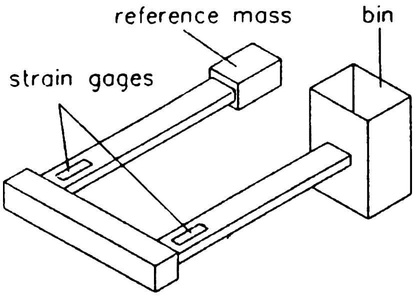

Figure 4. "Continuous" mass density measuring device (Böttinger, 1990).

is periodically brought into the grain flow by the aid of an hydraulic cylinder. When the sample was weighed at different times during motion of the sensor, the maximal error remained ±1%. Major drawback of this sensor seems to be the discontinuous measurement, caused by emptying periodically the box.

Moisture content. To measure the grain moisture content in a site-specific way, capacitive, microwave or Near Infrared Reflectance (NIR) measurement devices are used. The main problem of capacitive and microwave measurements is the dependence of other parameters as mass density and temperature. Moreover, microwave measurements are expensive. Recently, good results were reported with a NIR sensor, used for both proteïn and moisture measurements.

The DMC capacitive moisture sensor (Figure 5) is used in different commercial "precision farming" packages. The sensor is mounted on the auger that transports the clean grain to the grain bin. To obtain a constant filling of the auger, the auger flights are removed above the sensor. Under difficult harvesting conditions (wet and unripe grain), the absence of the flights can block the auger. When calibrated with destructive moisture determination of hand taken samples, research conducted by the authors showed a maximal error of 20% in wheat. The actual moisture content was determined using the oven drying method. Calibration seems to be different for wheat and barley.

RDS and AgLeader both include the DMC moisture sensor in their yield mapping system. In the RDS Ceres II system, the sensor is mounted in the centre or at the end of the tank feeding auger. AgLeader now offers the DMC moisture sensor with by-pass mounting configuration for the clean grain elevator.

John Deere developed its own capacitive moisture sensor, similar to the DMC sensor. The sensor is mounted in a bypass at the elevator. In the bypass, an electrically driven wheel is fixed under the sensor to control the amount of grain in the sensor.

The Micro-Trak sensor does not rely on grain contact, and is located at the end of the tank-loading auger.

Protein content. In 1997, results were reported on tests with an on-the-go protein- and moisture-sensor, produced by Milestone Technology with commercial availability to follow.[10] The manufacturer claims a precision of ±5%, 95% of the time, for both the measurement of moisture and protein-content. The sensor is mounted on the auger in the grain bin, and is based on a Near Infrared Reflectance measurement.

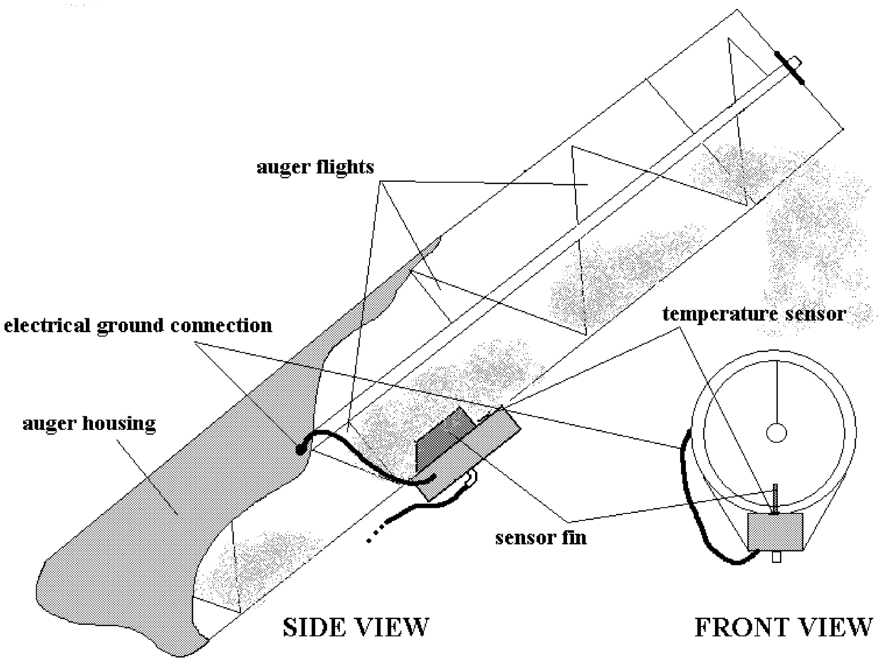

Figure 5. Capacitive moisture sensor.

For real-time grain analysis, a sensor has been described (Wright and Hood, 1998) which uses the NIR-principle to measure different grain parameters. The sensor was placed on a test machine at the end of the clean grain elevator. The sensor consists of a test chamber which is periodically refilled. The reflected light is scattered at different wavelengths by means of a diffraction grating. The scattered light is detected by a photodiode array. Each photodetector of this array detects energy within a desired bandwidth of the spectrum.

Additional information for the interpretation of yield maps

Lodged crop detection. Missotten (1998) detected lodged crop via a switch at the combine header. To pick up the lodged crop, the driver must lower the reel and hence a switch is pushed.

Crop density. Taylor *et al.* (1986) mounted a laser emitter and receiver at the cutter bar. The distance between emitter and receiver measured 80 cm. When grain stems pass in between the emitter and receiver, the signal is interrupted. The interrupt frequency is proportional to the number of stems per square meter at a specific ground speed. Unfortunately, the relationship was non-linear due to the increased overlap of different stems at high populations.

Missotten (1998) tested a similar sensor configuration with infrared sensors. Emitter and receiver were placed at a distance of 15 cm from each other. Similar problems

(Taylor *et al.*, 1986) were noticed when the sensor was not positioned at the right height in the crop canopy.

Straw moisture content. Strubbe (1973) and Van Loo (1978) developed a sensor to measure the straw conductivity. Two electrically isolated plates and the combine frame create an electrical field. As straw passes through this field, an electric current was generated proportional to the conductivity of the straw.

Missotten (1998) used this configuration to detect weed patches in the field. Because of the high moisture content, the conductivity of weeds is high compared to straw conductivity.

Conclusions

Over ten years ago, research for precision farming sensors on combines started with the grain flow sensor. Whereas various sensors are marketed around the world, research is still ongoing. One thrust of recent research is the comparison of the various commercial sensors. At the other extreme, the search for sensing technologies independent of crop type and field slope continues. Reliability and ease of use are important considerations, which need some improvements in most commercial systems. Otherwise the target group will be limited to the technically most advanced farmers.

Researchers continue to search for alternative measurement tools. A second thrust of the current research is to assess other yield parameters more accurately, such as the cutting width. Ultrasonic sensing seems to be a hot topic in research, but some problems (like with lodged crop) should be solved before they can be marketed.

Some researchers try to determine the grain quality attributes (protein content, mass density, moisture content) continuously because these influence market value of the harvested crop. Grain quality parameters may also help to explain the variation in grain yield. As the Near Infrared sensing technology seems to evolve fast, some new sensors can be expected soon. The success of the practical application in harvesters will greatly depend on how constructors will sustain the calibration of the system once it is mounted in the harvester. Ease-of-use and handling for the farmer is also very important.

Other research is focussing on biomass yield and straw moisture content, lodged crop and density, but the need of these factors is first to be proved.

The last three groups of sensors remain in the research phase. Strong growth in the precision farming sensor market can be expected as these technologies mature.

Notes

1. RDS Technology Ltd., Stroud Road, Nailsworth, Gloucestershire, England GL6 0BE.
2. Claas KgaA. Münsterstraße 33, D-33428 Harsewinkel.
3. Deere & Company, One John Deere Place, Moline, Illinois 61265-8098, (309) 765-8000.
4. Case Corporation, 700 State Street, Racine, WI 53404 USA.
5. AgLeader Technology, 2202 S. Riverside, Dr. Ames, IA 50010.
6. DEUTZ-FAHR Agrarsysteme GmbH, Deutz-Fahr-Strasse 1, 89415 Lauingen, Germany.
7. Micro-Trak, P.O. Box 99, 111 East LeRay Ave, Eagle Lake, MN 56024-0099 USA.

8. AGCO Corporation, Duluth, Georgia, USA.
9. Harvest Master Inc., 1740 N. Research Park Way, Logan, UT 84341.
10. Milestone Technology, Inc., 395 W. Hwy. 39, Blackfoot, ID 83221.

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