An approach to compensation of dust effects on seed flow sensors

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Abstrct: Optical seed mass flow sensors are widely used on seed drills, grain drills and combine. An important challenge in these sensors is their malfunction in a dusty condition. Dust caused by soil and seeds may sit on the light elements and disrupt its function. In this study, an approach was developed to compensate this effect. A non-contact intelligent system with infrared diodes and a microcontroller with ARM architecture was built up to monitor the seed flow in the delivery tube of seed drills. At the hardware phase, a glass with a different radius of curvature was installed in front of the elements. The semi-cylindrical glass placement in front of the optical elements meant that the arrangement was sealed against dust. Besides, the fall of the seeds tangential to the glass during the sowing caused the glass to self-clean. However, the hardware configuration of the seed flow sensor with semi-cylindrical glass alone was not sufficient under adverse dusty conditions. A suitable algorithm was therefore developed and applied to compensate for the dust effect. In this case, instead of the level of output voltage, MS (mean of variances) of sensor outputs was calculated. The mass flow estimation model was obtained using multiple regression between the MS index level of the seed flow sensor and digital scale data. Experiments were carried out using different types of seeds in several repetitions. In all tests, the correlation coefficient of the mass flow estimation model was obtained above 0.9. The results revealed that this system works correctly and precisely in dusty field conditions without having to clean the sensing elements.

Keywords: seed drill, seed mass flow, infrared sensor, dust

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1 Introduction

Planting operation is one of the most important phases of crop production, whose quality has a direct impact on crop yield. To guarantee the quality of this step, it is necessary to monitor the seed flow and use it regularly in mechanized cultivation. This monitoring should be carried out to identify specific performance conditions, such as additional seed planting, miss sowing, block seed tube, seed tank depletion, defective transplant system, etc., and ultimately increase the total land productivity. Recently, the use of precision planters for row crops has been rapidly increasing and there are many companies that produce these machines in the market. Performance test measurements should be carried out in order to control the functionality of these machines. the correct, automatic and rapid detection of precision planter performance is very important not only for manufacturers but also for researchers and users. With the growth of the

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population and the increase in food demand, it is necessary to carry out the production process of agricultural products accurately and efficiently (Ayaz et al., 2019).

In recent years, there has been a great deal of research on particle flow measurement using capacitive, electrostatic, microwave, radiometric, and optical sensors. Many researchers have worked on detecting and estimating seed flow on planters (Gautam et al.,2019). Field conditions are very different from laboratories and the sensors used in field operations should not be affected by environmental conditions. During field operations, the vibration of machines, loud tractor noise, dust, changes in temperature and humidity are always challenging factors. A capacitive seed sensor does not need to be cleaned continuously and because it does not come into direct contact with the seed, it does not damage the seeds. Compared to other seed flow sensors, the capacitive sensors cost less, but due to the effect of ambient temperature and humidity on the capacitive capacity, the sensor may fail. Seed flow electrostatic sensors are very similar to capacitive sensors. These sensors include electrodes that change the amount of induced charge on the electrodes as the particle flows, and produce a signal proportional to the particle flow. In acoustic sensors, the seed must strike a plate to produce the sound which is later processed and analyzed to estimate the mass flow of the seed. The possibility of seed damage and the noise during field operation make it not suitable for working in the field Ding et al. (2018) designed a monitoring system for planting small seeds such as canola. T

his system works by processing the signals caused by the collision of rapeseeds with piezoelectric film. used image processing to obtain the proper positioning of the piezoelectric film in the flow path of the seed. Two important results of this system are the insensitivity to mechanical vibrations and dust in field tests. Al-Mallahi and Kataoka (2016) used a fiber optic sensor to measure seed flow. The sensor includes a number of optical transmitters, optical receivers and an amplifier connected to the transmitter and receiver elements by optical fibers. Seed flow interrupts the connection between the receiver and the optical transmitter. Al-Mallahi and Kataoka (2016) implemented an algorithm to automatically correct the data output of the fiber optic sensor and estimate the masses in 0.8 seconds on the fiber optic sensor and developed the sensor. Cay et al. (2017) developed an opto-electronic measurement system to measure seed spacing in planters. This system calculates the distance between passing seeds by processing the signal caused by the seed passing through the space between the optical receiver and the transmitter. This system is not specific to seed with a certain size and it works for all kinds of seeds in different dimensions. This system was designed for laboratory tests and was not used in the field.

By comparing two methods of image processing and optical sensors to determine seed flow; Image processing is accurate, complex, expensive and not suitable for the field, but optical sensors are low-cost, accurate and usable in field conditions. Che et al. (2017) designed a type of photoelectric sensor that included transmitter and receiver infrared diodes. In this system, when the seed passes through the infrared diodes, the amount of infrared radiation received by the receiver diode is changed and the system calculates the number of seeds flowed by processing the generated signal and displays it on the LCD monitor. This system was able to display the seed flow rate and the blockage of the delivery tube in the field. Raheman and Kumar (2015) used the infrared integrated circuit sensor and the Arduino board to detect the seed flow in the seed tube of seed drills. As the seed passed through, the infrared beam was reflected back to the sensor and the seed was detected. Kumar and Raheman (2018) developed a new system that not only recognizes the flow of seeds, but also the blockage of the seed tube. In the new system, they put the infrared transmitter and receiver together and apply an appropriate algorithm to the processor. The system uses two detectors for each fall pipe. Knaus and Palzenberger (2018) developed a seed drill monitoring system. To do this, they used an infrared sensor to monitor seed tubes, and they also used piezoelectric sensors to detect clogged fertilizer tubes. In addition, the system had the ability to load prescription planting maps and could operate based on prescriptive planting plans using the Global Positioning System. They have used the dual-wire CAN bus protocol to transfer data. Liu et al. (2019) developed an intelligent infrared sensor. In this study, a sensor was developed based on a seed flow reconstruction technique to monitor seed flow. This technique can reduce the measurement errors caused by the seed overlapping.

There are two plates and a grid in the flow path of the seed. The seeds can only cross the grid individually, thus measuring the flow rate of the seed. In the seed drills, any kind of obstacle in the seed flow path is not appropriate and blocks the seed flow path. Körösi (2020) designed an infrared seed flow sensor for a pneumatic seeding machine and claimed that the sensor works longer without a dust problem in field conditions. Using reference data that record the proper time and place, as well as amplifying the intensity of infrared rays in the event of dust sensing, the sensor has established the seed flow for working in dusty conditions. They designed the seed flow sensor for a pneumatic grain drill, in which the seed flow sensor system is more distant from the soil and the airflow makes the sensor stay clean for longer. The sensor alerts the operator if needed, and the operator cleans the sensor through a cleaning gate. In mechanical seed drills, the seed flow sensor is installed near the soil on the seed tube and thus the negative effect of dust on the seed flow sensor in mechanical seed drills is more than on pneumatic grain drill. The divergence issue is usually solved using a sheath (Besharati et al., 2019; Körösi, 2020).

Dust laid on diodes can disrupt their performance. The dust on the transmitter blockages a part of radiation emission and the dust on receivers was detected as a seed. Karimi et al. (2019) revealed that the obstruction of the optical elements by dust has an adverse effect on the performance of the optical sensing system. Besharati et al. (2019) designed an IR seed sensor to detect flowing seeds through a delivery tube and estimate the flow rate. They extracted the relation between the receiving voltage from the seed sensor and seed mass flow. Then, developed the model for estimation of seed mass flow based on physical properties of seeds and the corresponding voltage changes. This sensor estimates the mass flow well, but after a while, dust negatively affected the sensor's performance. A cleaning gate usually was used to clean the sensor if needed (Besharati et al., 2019; Karimi et al., 2017; Karimi et al., 2019). For small seeds, the miscounting of seeds during monitoring happens frequently when using conventional seeding quantity sensors. Most optical seed flow sensors fail to determine the flow rate of fine seeds and overlapping seeds, therefore, Liu et al. (2019) proposed a seed flow sensor and a seed counting algorithm. In the developed seed counting sensor, the seed flow is guided through a narrow slit that includes an infrared receiver and a transmitter. The signal related to small particles (non-seeds) and the signal related to two successive falling seeds were obtained in the experiments and applied in the seed counting algorithm. Zhao et al. (2020) designed an arc array seeding flow sensor based on piezoelectric ceramics for air flow conveying seeder. They used CAN two-wire communication to measure and display the seed flow momentarily.

In order to prevent the reduction of planting quality, the planting operation must be monitored immediately. It is time-consuming and tedious to work in the field, so some researchers tried to eliminate the dust effect by software. In seed drills where the seed flows in bulk, it is not possible to count the seed and the mass flow of the seed must be estimated. In recent years, many studies have been conducted by researchers on seed flow sensors, which are based on studies that use optical sensors with infrared elements to monitor seed flow. However, the negative effect of dust on estimating seed mass flow must be eliminated. Based on previous research, hardware retrofit and software dust compensation can be expected to provide an inexpensive and good-performing sensor that can operate in poor dust conditions without the need for sensor cleaning.

A seed flow sensor must have the ability to work in the field, be reliable, low-cost, and applicable to all kinds of seeds. In planting machines, the path of seed fall should not be limited.

2 Materials and methods

The experiments were carried out in the precision agriculture laboratory of University of Tabriz in 2019. The sensor frame was designed using Solidwork 2018 software. Also, the seed flow sensor circuit was designed using Atium Designer 16 software. The required algorithm for the sensor microcontroller was created with the following software: MPLAB version 3.4, PIC C Compoiler version 5.04 and Keil uVision5. By using the test platform, seed flow was created from the delivery tube and data collection was done at different seed flow rates. The sensor data was analyzed using Excel 2013 software and the obtained regression equation was applied to the microcontroller.

2.1 Seeds and test platform

Experiments were carried out using seeds that were regularly sown with seed drills. Chickpea and alfalfa seeds, wheat and barley grains were used for laboratory calibration and tests (Figure 1). The field test was done using wheat grains. These seeds and grains were representatives of small to large seeds (Table 1).

Table 1 Physical properties of seeds and grains

Properties	Type of seeds and grains			
	Chickpea	Barley	Wheat	Alfalfa
Length (L), mm	10.52	9.18	6.42	2.16
Width (W), mm	7.66	3.16	2.74	1.43
Thickness (T), mm	8.34	2.45	3.22	0.87
Equivalent diameter (ds), mm	8.76	4.13	3.84	1.39
Sphericity (S_p)	0.83	0.45	0.59	0.64
Weight per 1000 seeds, g	422.4	43.38	39.60	2.30

Alfalfa Wheat Barley Chickpea

Figure 1 Seeds and grains used in experiments

The test platform used in this study is a single-row sowing unit (Figure 2

Figure 2). This platform is equipped with a seed metering device, seed tank, feed gate lever, adjustable feed gate and seed tube. It is driven by a 0.5 kW electric motor. The power transmission system contained two pulleys with diameters of 300 and 50 mm. Electric motor speed and sowing rate are controlled using a variable frequency drive (VFD). The VFD frequency can be varied from 1 to 30 Hz to provide the slowest to the fastest speeds required for rotations.

The data acquisition contained a digital scale (accuracy 0.01), one-row sowing unit, a laptop, a seed flow sensor and a USB to TTL Serial Cable. As the VFD increases the speed of the electric motor, the mass flow of seeds increases at the same time. Using a digital scale, the mass flow rate of the seed was calculated in g/s for different electric motor speeds. The sensor data was saved and transferred to the laptop via the USB-TTL serial cable.

Figure 2 The experimental platform

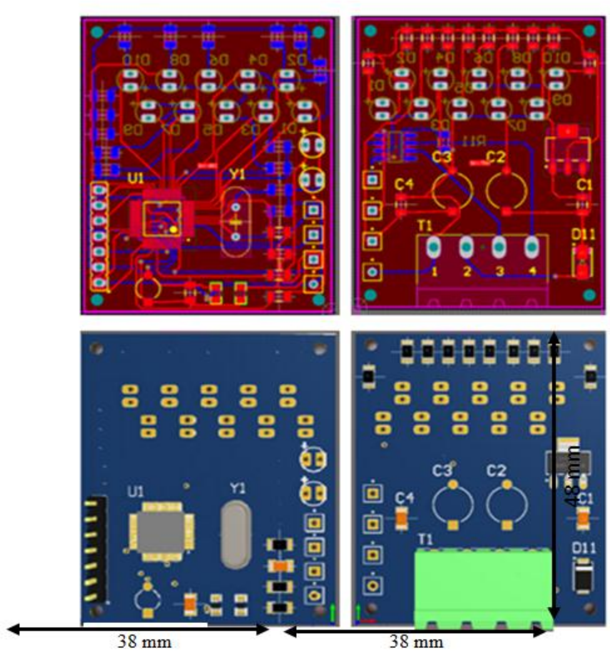

Figure 3 Infrared transmitter and receiver circuits

2.2 Sensor development

The optical seed mass flow sensor was developed based on an infrared transmitter and a receiver circuit. The receiver circuit consists of ten infrared receivers and the transmitter circuit contains ten infrared transmitter diodes. The two circuits are located in the seed flow sensor shell facing each other. Required components were prepared and soldered onto a circuit board. The components used include a microcontroller (STM32F103C8T6: 64kB flash memory capacity, 72MHz clock frequency, 20kB SRAM memory capacity, 2-3.6V DC supply voltage), a CAN (controller area network) bus chip, infrared transceiver diodes, optical diodes, rectifier diodes, a 3.3V regulator, and other electronic components. The voltage resolution of an ADC is equal to its overall voltage measurement range divided by the number of intervals (Eqation 1). The reference voltage of the microcontroller was 3.3 V and it had a 12-bit resolution.

Q=v_ref/(2^n-1)=3.3v/(2^12-1)=0.00081v (1)

where,

Q=ADC voltage resolution (V),

v_ref= overall voltage measurement range (V), and

n=ADC's resolution in bits (bit).

The microcontroller was selected for the seed flow sensor because of its high memory, high resolution and processing speed and support for the CAN bus protocol. The seed flow sensor circuit was designed and printed (Figure 3).

2.3 Frame design with the ability to install glass

The three-piece sensor frame, printed by a 3D printer, was designed to provide an easy installation of glass and circuits (Figure 4). The frame is designed so that the dust does not penetrate the electrical circuit of the sensor (Figure 5). In the frame, the emitting diodes face the diodes of the receiver. The flow of seeds changes the intensity of the light received by the receiver, resulting in a signal, which is proportional to the flow of seeds. The propagation angle of the infrared transmitter elements could cause the light of one transmitter element to affect other receivers that are not co-axial with the transmitter. A sheath has been used to reduce the propagation angle and prevent radiation interference.

Due to the dusty state caused by the passage of seeds in the seed tubes and the operation of the seed drill in the fields, the sensing elements need to be covered with a shell. This coating should be able to pass infrared rays and prevent dust from passing through the sheaths.

To prevent laying the dust on diodes, a glass cover was installed in front of the diodes. Glasses with a size of 13×33 mm and curve radiuses of 9, 10 and zero millimeters were investigated. They were mounted and tested on 3 sensors (Figure).

The sensor frame is designed in such a way that after installing the glass, the diameter of the inner space of the frame is not smaller than the diameter of the delivery tube so that there is no obstacle for the passage of the seed.

2.4 Development of a dust-resistant algorithm

The dust that stays in the path of the infrared beams misleads the sensor. To solve this problem, an algorithm was used to accurately detect the seed flow rate despite the dust. So that instead of detecting the seed flow based on the output voltage values, an algorithm based on the changes in the acquired signals was developed. Eventually, an index level is generated which determines the state of seed flow in the seed tube.

The MS, MM and MX index level are derived from the following Equations 2-7. (Bruce et al., 2020; Gelman and Hill, 2006).

$$vara_i = \frac{\sum_1^{100}(xj-\bar{x})^2}{n} \tag{2}$$

$$MS = \frac{\sum_1^{10} vara_i}{10} \tag{3}$$

$$mma_i = \frac{x_{min}-max\,(x)}{max\,(x)-min\,(x)} \tag{4}$$

$$MM = \frac{\sum_1^{10} mma_i}{10} \tag{5}$$

$$mxa_i = \frac{x_{max}-max\,(x)}{max\,(x)-min\,(x)} \tag{6}$$

$$MX = \frac{\sum_1^{10} mxa_i}{10} \tag{7}$$

where,

$vara_i$= the variance of 100 data for each of the 10 diodes,

a_i= outputs of each of the 10 diodes, i=1, 2, …, 10, (V),

x_j:=each value of dataset, $j = 1, 2, \ldots, 100$, (V),

$\bar{x}$ =the arithmetic mean of the data(V),

n=the total number of data points,100,

mma_i= the normalized value,

$max(x)$= maximum reference data(V),

$min(x)$=minimum reference data(V),

x_{min}= an original value,minimum set of hundred a_i, (V),

mxa_i= the normalized value, and

x_{max}=an original value,maximum set of hundred a_i, (V).

The dust-resistant algorithm for estimating the seed mass flow is designed as follows (Figure): The seed flow sensor has 10 infrared receiver diodes that are connected to 10 microcontroller input pins. 100 memory spaces are allocated for each infrared diode. The microcontroller read and stored the 100 voltages from each infrared receiver diode.

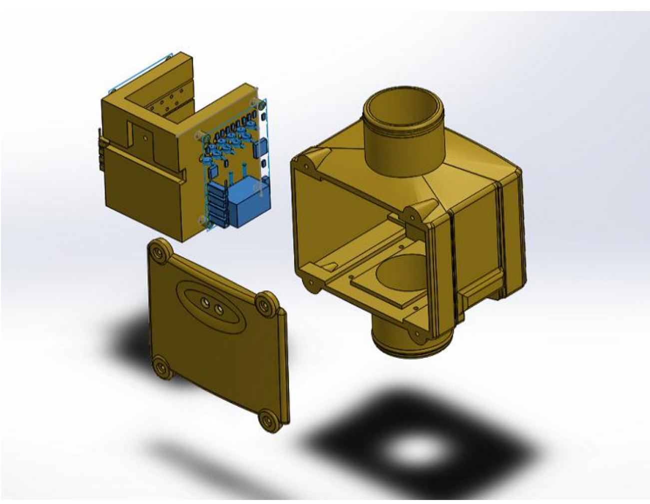

Figure 4 Seed flow sensor frame designed in SolidWorks

So that with each data collection from the seed flow sensor, 1000 voltage data from 10 infrared diodes are obtained. Data is then processed to calculate defined index levels. Further analysis would determine one of three conditions: 1) seed flow, 2) no seed flow, and 3) blockage in the seed tube. If the seed flow status is determined, then the seed mass flow is estimated using the MS index level (processing takes a maximum of 0.4 seconds). The system is updated every 0.4 seconds and displays one of three modes. With n = 100, the update time is 0.4 seconds. As n increases, the update time also increases, which is not desirable.

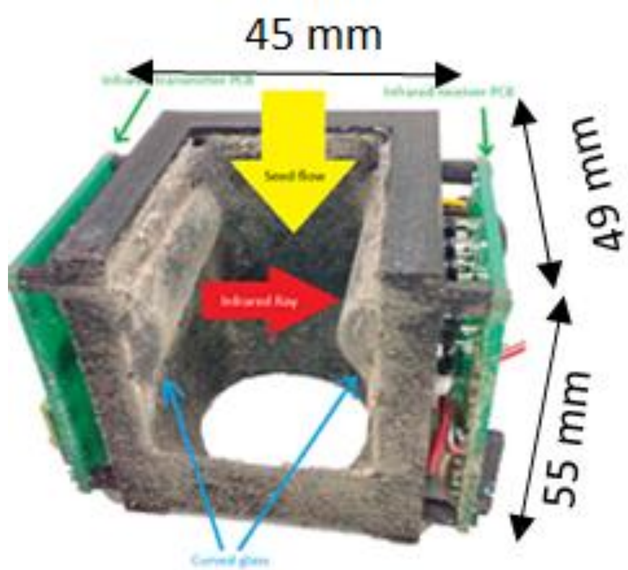

Figure 5 The main part of the seed flow sensor

2.5.1 Glass selection experiments

For selecting the appropriate glass, the tests were carried out with three sensors. Glasses with different diameters were installed on each. Dusty barley (used for animal feed) was chosen to conduct experiments. In this case, 13 grain flow rates of dusty barley grains in 5 replications were investigated. All 13 flow rates were included sequentially in one test. The glass was cleaned before each replication. The data acquisition code was implemented, and the metering device was operated by the electric motor at the first speed (so first-rate). After approximately 3 min, the electric motor was operated farther to the next speed to obtain the second flow rate. This was repeated until the highest flow rate was achieved. In this experiment, the average mass flow for all stages of the experiment, was measured using a digital scale and a timer. Correlation between grain flows and sensor output was the criteria for the glass selection.

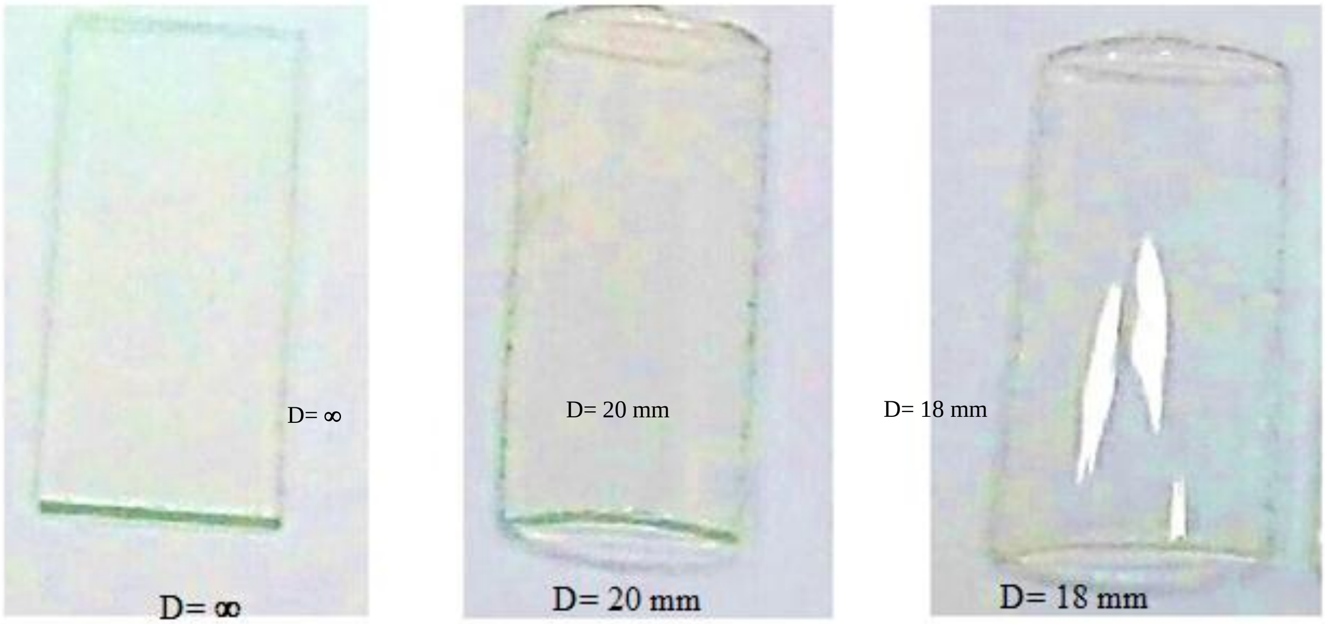

Figure 6 Curved and flat glasses tested in dust conditions

2.5 Experiment

2.5.2 Experiments to select the appropriate index level in the algorithm

An experiment was performed to compare the three index levels of MS, MM and MX using the selected glass cover. In this stage, three conditions were created: 1) seed flow, 2) no seed flow, and 3) block seed tube. The sensor output signals were processed in the microcontroller and the mentioned above three index levels were simultaneously calculated and sent to the computer. This experiment was performed for barley, chickpea and alfalfa seeds in five replications; some of the relevant results are shown in the Figure 6 and Figure 9.

2.5.3 Experiments to obtain the regression equation

To find the relationship between mass flow and MS index level as well as the relationship between mass flow and the data of ten infrared receivers of each sensor, four seeds: alfalfa, wheat, barley and chickpea were tested in five replications. One phase of non-flow, one phase of seed tube blockage, and six phases of seed flow at different mass rates were recorded in each replicate. Each step was taken for three min. The average mass of flowing seeds for each step was measured using a digital scale.

The regression model was calculated in the following two ways:

Using the mean MS index level of ten diodes and the masses measured by the scales, the regression equation for estimating the mass flow of seeds was obtained.

Using the MS index level of ten diodes and the masses measured by the scales, the multiple regression equation for estimating the mass flow of seeds was obtained.

2.6 System outline

The seed flow measuring system has a sensor for each seed tube. In field conditions, excessive wiring in devices is very undesirable, and the system is exposed to noise. Hence the serial bus transmission network, Wi-Fi transmitter and Android application were used to monitor seed flow status in fall tubes. The CAN Bus network can transmit data from 33 sensors using only two wires. The status of the seed flow in the seed tube is displayed momentarily (Figure 8).

The seed flow monitoring system was tested in the field with HASSIA seed drill (Figure 9). During the experiment, zero to very high mass flow rates were applied. Despite the adverse dust conditions, the sensors worked properly on the farm.

3 Results and discussion

3.1 Glass selection

The scales and seed flow sensor data were standardized using Equation 8 where the value of the score Z will be negative if the scale data is less than the average. Data standardization helps ensure that their importance does not depend on their unit of measurement, and enables us to compare data with different units. The standardized data from the sensors and scale was shown in Figure in three replications. The sensor output follows the scale data well but is affected by dust. The lowest coefficient of R^2 is for the sensor with flat glass. The highest R^2 coefficient with a value of 0.89 is for the sensor with the 18 mm diameter glass (Figure). The results indicate that the performance of the curved glass sensors is better than the flat glass sensor and the 18 mm glass sensor performs better than the 20 mm glass sensor. The amount of dust sitting on a curved glass was less than flat glass. This is because some seeds hit the curvature of the installed glass, causing it to self-cleaning in the sowing process. This was confirmed by visual observation, too.

$Z = \frac{x-\mu}{\sigma}$ (8)

where,

Z=standard score,

x=the initial data ,

μ =mean of the x, and

σ=standard deviation of x.

3.2 Selecting the appropriate index level

Three index levels of MS, MX and MM were calculated for the seed flow data. Figures 11-13 show the MS, MX and MM index level values under three conditions of seed flow, no seed flow and blocked seed tube. As can be seen, the MS index level can better illustrate the difference between the three modes. Since the MM index level estimated for barley seeds under no seed flow and seed flow conditions are close to about 300, the index level cannot distinguish between no seed flow and seed flow status. According to Figure 8, the values of barley seeds in the three mode of seed flow, no seed flow and tube blockage are about 450, 350 and 500, respectively. Due to the closeness of these numbers, it is concluded that the MX index level may not be able to correctly identify the three conditions. This is while the MS index level is always estimated to be zero in the tube block mode, and about 70 is obtained in the no seed flow mode and is estimated to be about 25,000 in the seed flow mode. In addition, the MS index level increases or decreases in the same way as the seed rate increases or decreases (Figure 6 and Figure 9).

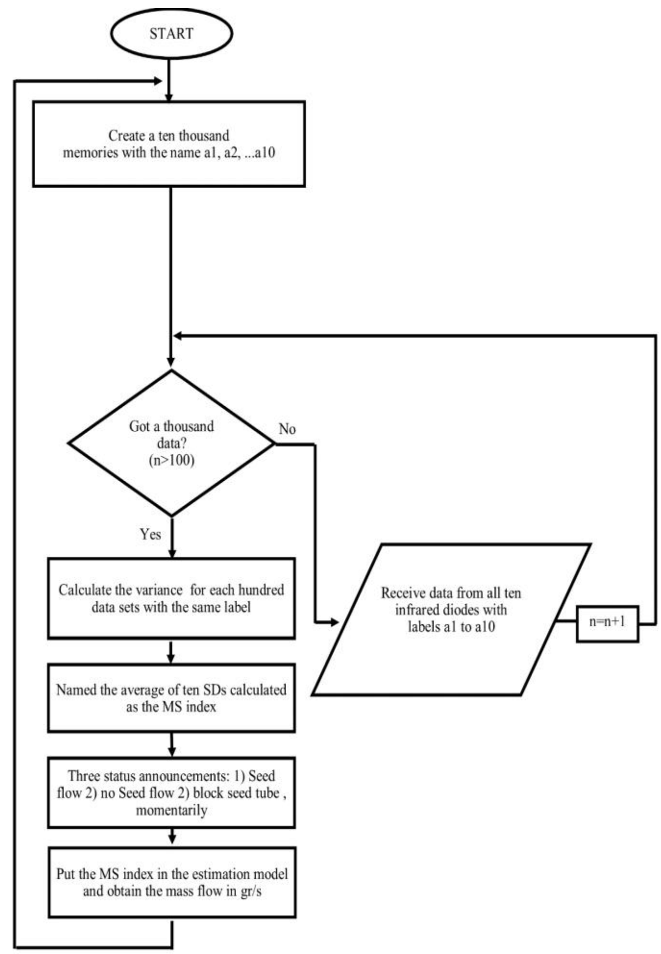

Figure 7 Algorithm used in the seed flow sensor

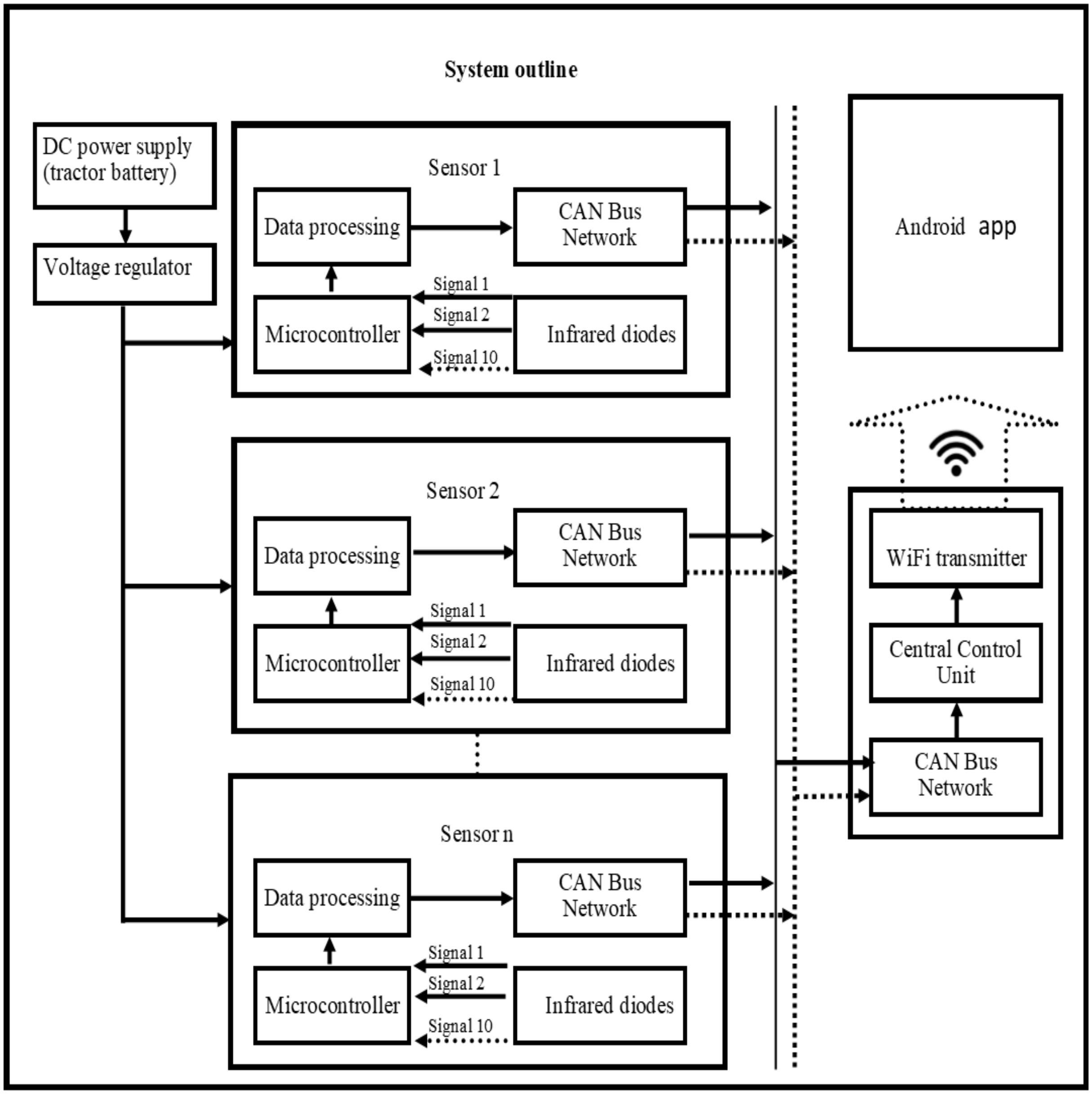

Figure 8 Seed flow monitoring system for seed drills

3.3 Regression model

An experiment was conducted at different mass rates.

The data were also collected in the cases of no seed flow and blockage of the seed tube. The sensor outputs at different statuses for barely (for example) were shown in Figure 9. As be seen, the data on the no seed flow case did not change before and after seed flow. This indicated that the dust did not affect the sensor.

Figure 9 Field testing of seed flow sensors

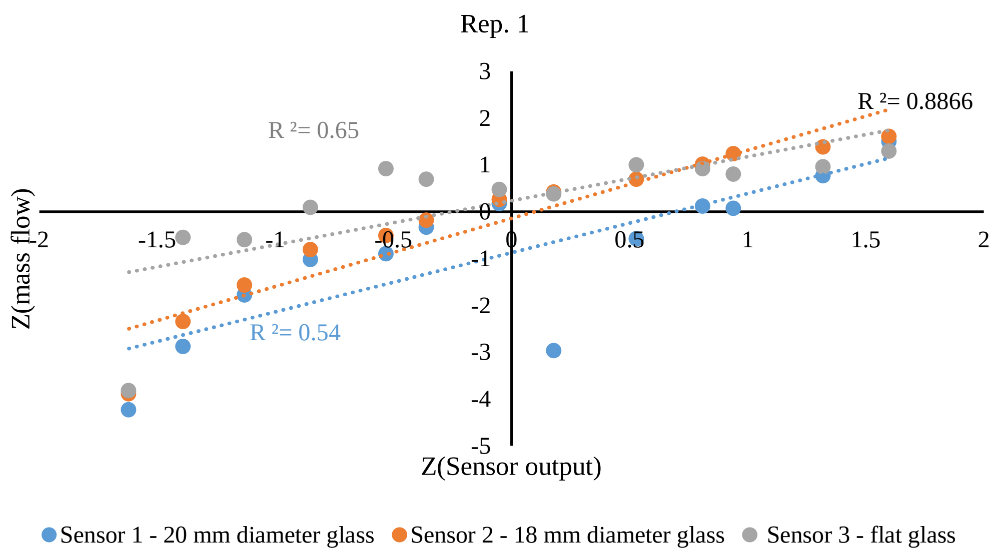

Figure 10 Linear regression graph of mass flow data and seed sensors

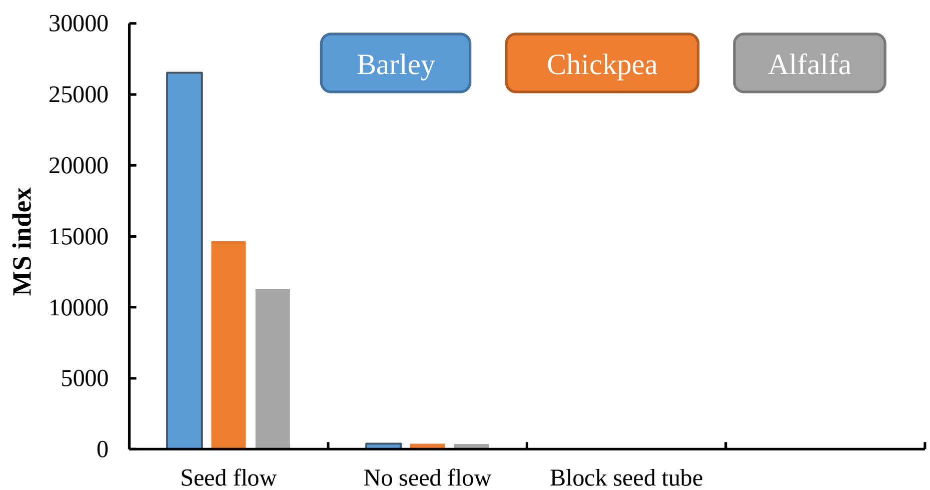

Figure 6 Changes in MS index level in different situations

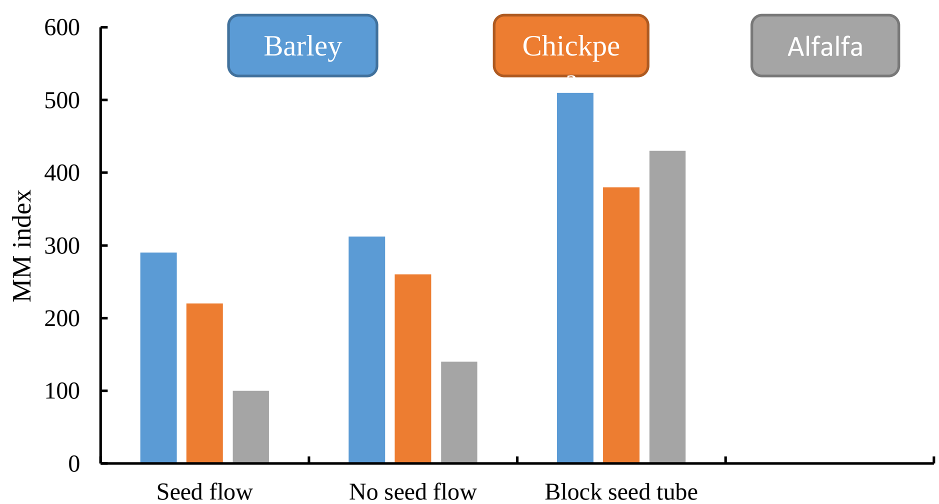

Figure 7 Changes in MM index level in different situations

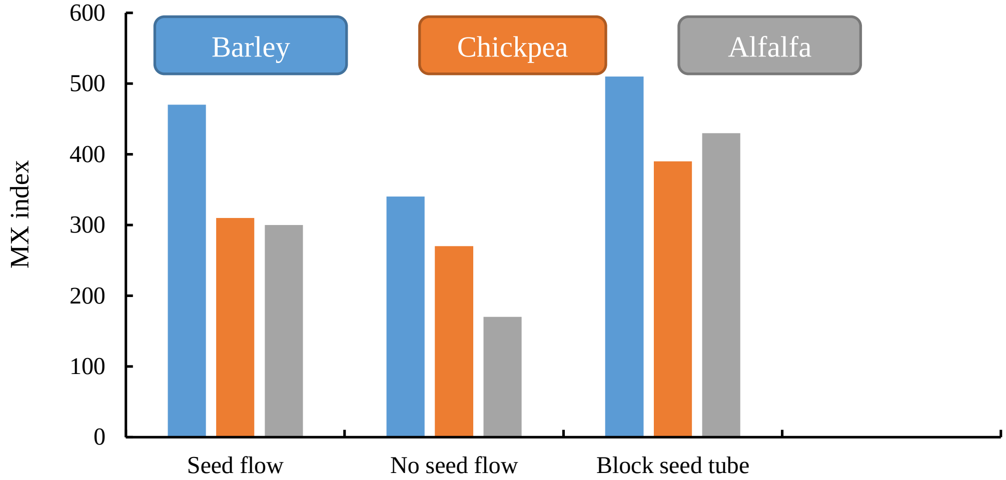

Figure 8 Changes in MX index level in different situations

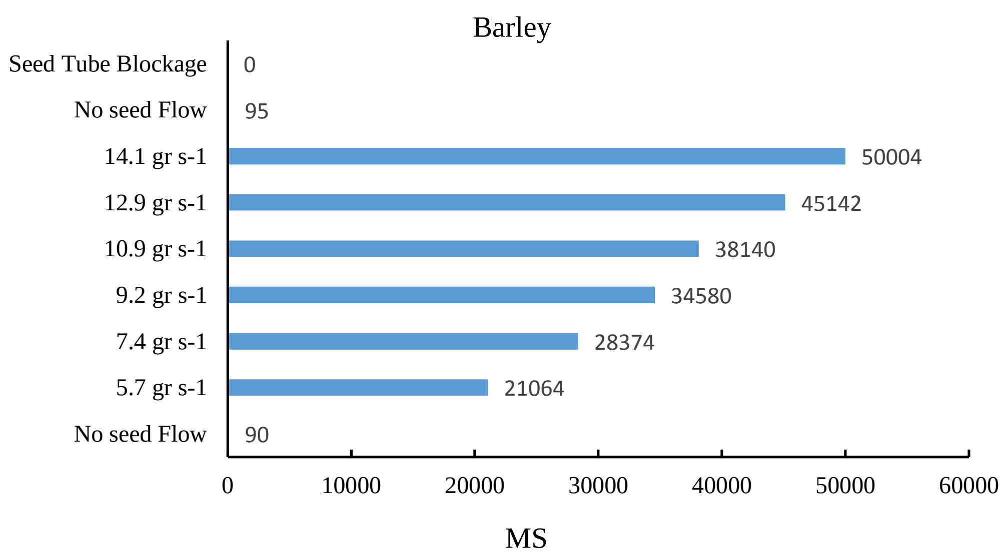

Figure 9 Seed sensor data at different mass rates

For estimation of the seed mass flow, the trend between seed mass flow and MS index level obtained from the seed flow sensor data was created for the chickpea, barley, wheat and alfalfa (Figure 10 - Figure 13). There are well-fitting and the correlation coefficient is high for all 5 replication (Table 2). As the seed rate increases, so does the MS index level. The model for estimating seed flow rates for different seeds is not the same, but the correlation coefficient is very high for all seeds. In general, the researchers' results show that infrared sensors can measure the sowing rate of seeds but may face problems under field operating conditions (Karimi et al., 2019).

Each seed flow sensor has 20 infrared diodes (Transmitter and receiver) and it transmits 10 voltage signals to the microcontroller. Instead of calculating the mean of the variance changes of 10 voltage signals, developing a model based on individual signals received from each sensor element can lead to better results. In the experiments that were carried out with four seeds and grains: Chickpeas, barley, wheat, alfalfa, simultaneously with the calculation and recording of MS index level, 10 variance data (Equation 2) from ten photodiode receivers were also stored separately in Excel format. A multiple regression equation between the 10 sensor signals and the mass flow was obtained using Excel 2013 software. The obtained model has a high coefficient of determination (R^2). This can be seen in Table 3. The multiple regression equation obtained is as follows, whose coefficients are given in Table 4 x_1 to x_{10}, which is the data for the 10 sensor infrared diodes, fall into the following Equation 9, y is obtained in grams per second.

$$y = a1x_1 + a2x_2 + a3x_3 + a4x_4 + a5x_5 + a6x_6 + a7x_7 + a8x_8 + a9x_9 + a10x_{10} \quad (9)$$

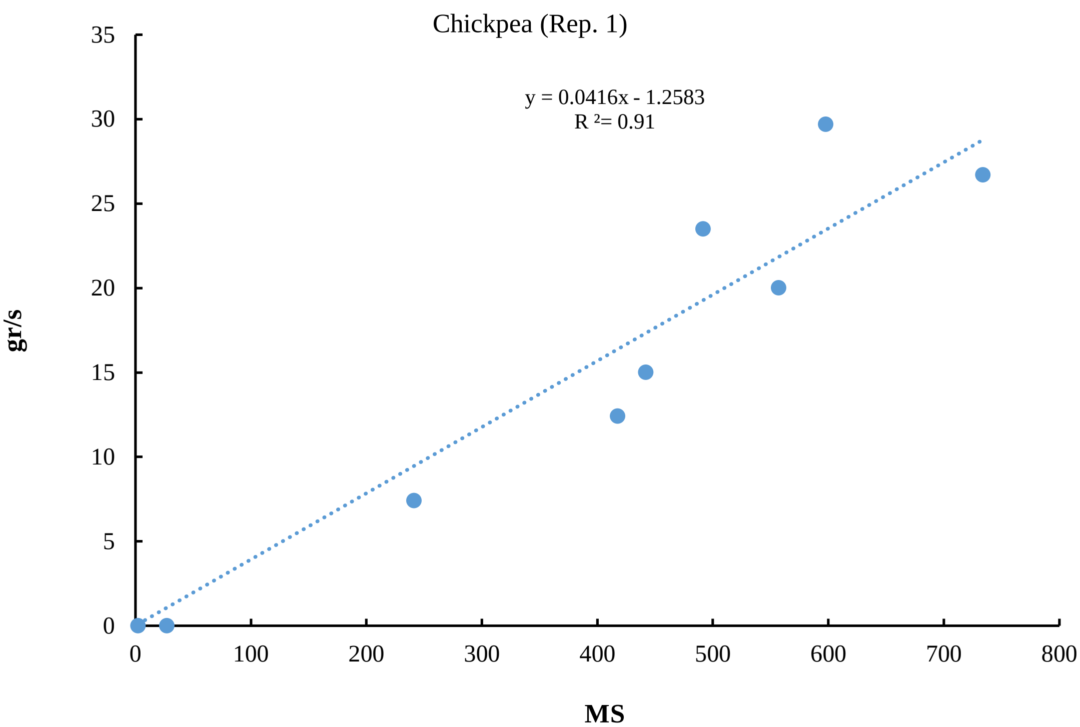

Figure 10 Relationship betwen mass flow and MS index level for chickpea

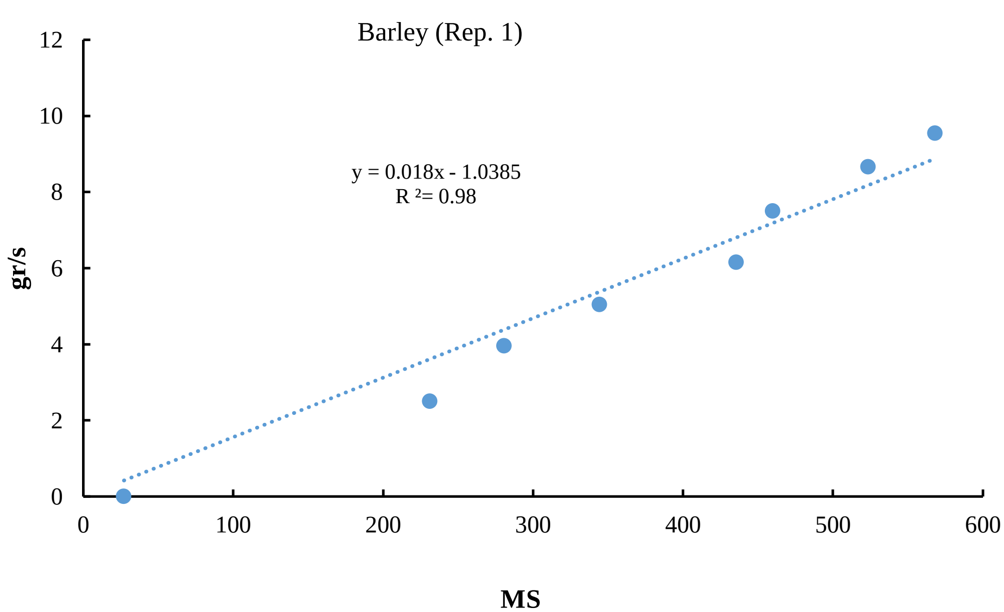

Figure 11 Relationship between mass flow and MS index level for barley

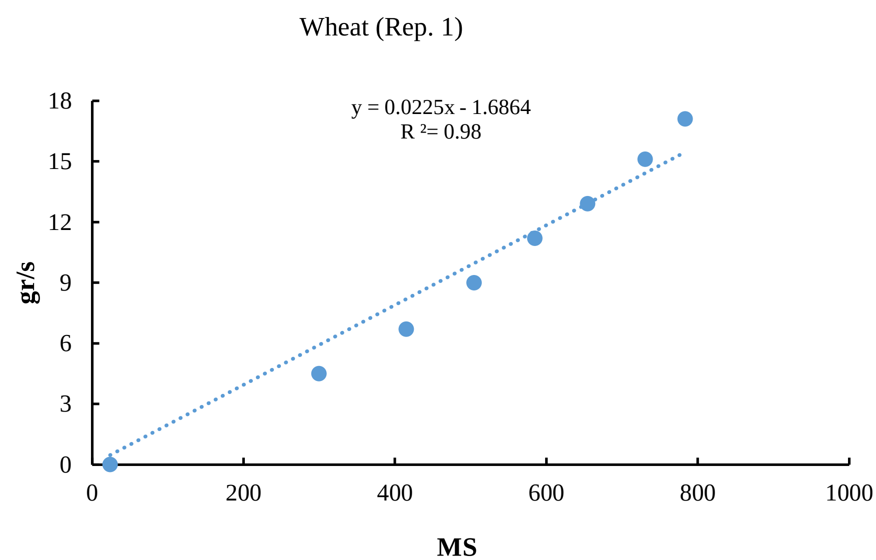

Figure 12 Relationship between mass flow and MS index level for wheat

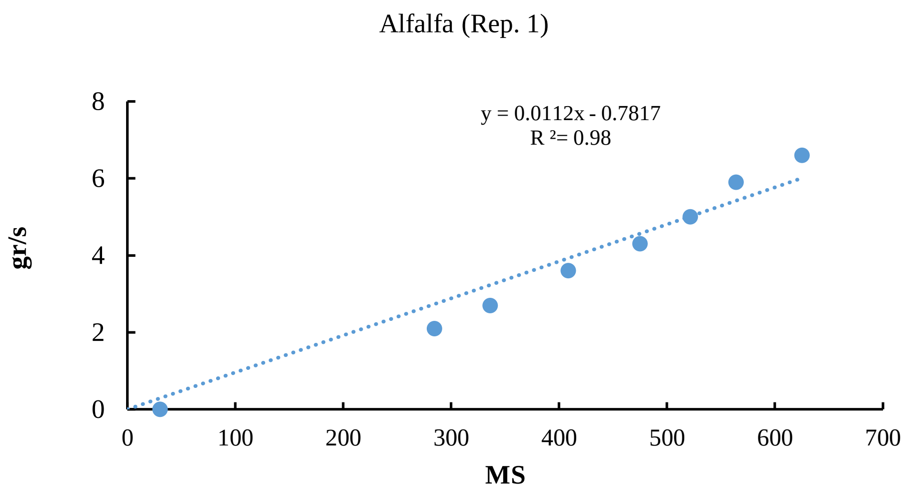

Figure 13 Relationship between mass flow and MS index level for alfalfa

Table 2 coefficient of determination for tested seeds

Seed or grain	R^2				
	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5
Chickpea	0.91	0.98	0.97	0.96	0.98
Barley	0.98	0.92	0.99	0.96	0.95
Wheat	0.98	0.97	0.97	0.96	0.96
Alfalfa	0.98	0.96	0.96	0.97	0.98

4 Conclusion

Many studies have been carried out to assess the seeding quality using optical sensing elements. In field operation, these sensors are exposed to the negative effect of dust, which influences the effectiveness of optical elements in the sensing and estimating of seed mass flows. Given the importance of the issue, in this study, a dust-resistant seed mass flow sensing system was designed. The use of a combination of hardware retrofitting by installing a curved glass and developing software dust resistance algorithms using signal changes as an index level rather than output voltage values has been considered. The test results of the development of an

IR seed flow sensor system with a coefficient of determination above 0.9 were completely satisfactory. The developed seed flow sensor works well in field dust conditions without the need for cleaning. The use of the high-resolution microcontroller with high processing speed and power to receive analog signals from sensor elements and the multiple regression model also improved the ability of the sensor to determine the seed mass flow rates. In view of the following suggestions in future work, including the use of lenses to concentrate and amplify the infrared radiation and the development of a suitable software algorithm to eliminate the effect of defective diodes during operation, the performance of the proposed seed sensing system could be further improved.

Table 3 Summary of multiple regression outputs (barley)

Regression Statistics	
Multiple R	0.996
R square	0.993
Adjusted R square	0.957
Standard error	0.638
Observations	40

Table 4 Ten coefficients obtained for the regression model (barley)

	Coefficients
Intercept	0
a1	0.2798
a2	-0.0169
a3	-0.0095
a4	0.0593
a5	-0.0895
a6	0.0158
a7	-0.0191
a8	0.0470
a9	-0.0860
a10	-0.0636

The developed seed flow sensor can measure the mass flow of all kinds of small and large seeds or grains independly their size. Different flow rates and seed overlaps in the sensor detection space did not affect the performance of the seed flow sensor. The curved glass and new alghorithm could compensate the dust effect.

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