Achievements and Perspectives in Precision Agriculture with the Multi-Crop Seed Sensing Module

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Abstract- This research investigates the field of precision agriculture, where the utilization of innovative techniques significantly enhances planting efficiency and agricultural yield. The primary objective of this study is to investigate the conceptualization, creation, and assessment of a comprehensive seed-counting mechanism incorporated within agricultural equipment. A comprehensive set of carefully conducted experiments was carried out, involving adjustments in key factors like power take-off (PTO) RPM, tractor RPM, and seed size. The results emphasize the crucial significance of the design, namely the dimensions of the apertures in the counting disk, which have been identified as a significant determinant of counting precision. Furthermore, the experiments shed light on the importance of obtaining sensors of superior quality to guarantee accurate seed detection, thereby underscoring the integration of mechanical and electronic elements in contemporary precision agriculture. Furthermore, the experiments revealed the significance of maintaining constant system conditions, as intermittent vacuum dips were detected. This study also demonstrates the possibility of improving performance by novel cover alterations, offering practical insights for optimizing systems. In general, the research is consistent with the existing body of literature that highlights the transformative capacity of technology in contemporary agricultural methods. It provides a captivating preview of the potential future developments in precision agriculture. The seed counting system, as described in this research, is a promising innovation with the potential to revolutionize agricultural planting and enhance resource efficiency. This improvement has significant implications for the sustainability of agriculture.

Index Terms- *Precision agriculture, seed counting system, design, trial evaluation, sensor quality, vacuum fluctuations, optimization, resource efficiency, sustainability*.

I. INTRODUCTION

Modern advancements in technology have prompted a sea change in the agricultural industry. In particular, precision agriculture has shown promise as a means to combat rising global food demand and dwindling supplies. It has become clear that using human labor to plant seeds is inefficient in this setting, as it results in uneven sowing, poor crop production, and excessive use of scarce resources. While the use of in-planter seed metering systems has helped to some degree, there is still a significant void: the need for a reliable Seed Sensing Module to improve seed identification, placement precision, and overall productivity. The urgent need to close this gap and promote precision agriculture drives this study's efforts to design, construct, and evaluate a low-cost Seed Sensing Module. Seed loss, irregular spacing, and poor placement are just a few of the issues that this module intends to address in the name of promoting sustainable agricultural practices and guaranteeing food security for a growing population.

Agriculture plays a major role in the worldwide economy and is the backbone of the economy of many developing countries. Agriculture is one of the biggest contributors to Pakistan's economy. It accounts for about half of the employed labour as it contributes about 22.7% to Pakistan's GDP [1]. It is also a substantial source of foreign exchange earnings. That is why the majority of the population is dependent on this sector. The need to generate more food for a swiftly growing population is creating pressure on crops and a negative impact on the environment [2]. An increase in agricultural techniques, i.e. applying Precision agriculture (PA) techniques will directly help elevate the economy and give a chance to increase careers for the labor force.

Precision agriculture (PA) is the use of high-technology sensors and electronic tools to help boost crop yields and assist in management decisions [3]. By adopting PA, the yield of the field grows to a bigger extent. An increased yield from 8 to 34 percent has been observed [4]. In Pakistan, there is a wide gap between the potential and the actual yield level [5]. This necessitates the promotion of precision agriculture to achieve the intended benefits.

Precision seed planting is becoming the main factor and developing direction of modern seeding technologies with the recent development of Seed Planting using PA techniques. Precision seed planting aims to improve agricultural productivity and reduce environmental risks by achieving precise seed distribution and using a requisite number of seeds in the planting process. Precision seed planting output increases by 10 to 30 percent compared with that of conventional seed planting [6].

The success of planting precisely with precision seed planting depends upon a Seed Metering Unit (SMU). SMU is used to carry seeds from the seed hopper to the seed delivery system that transfers the seeds onto the seedbed [7]. It is one of the most important parts of a precision planter and its performance directly influences the singulation and uniformity of seed distribution [8]. A seed meter consists of a hopper, seed disk, seed singulation, a seed delivery mechanism, a seed monitoring sensor, and a chamber that holds all the components. A precision planting seed metering unit and its components can be seen in figure 1.

Figure 1: Seed Metering Unit, eSet Meter by Precision Planting

Electronic metering units based on sensors can minimize the loss of costly seeds and help determine the population properly. In this regard, a seed sensing module is needed for better seed singulation in the field. A Seed Sensing Module (SSM) is made of a seed monitoring sensor and seed delivery mechanism. The seed delivery mechanism is a tube that directs the falling seeds to the seedbed and holds the seed monitoring sensor. SSM is placed at the opening of a seed meter. It is the most important component of a seed meter which is responsible for the detection and counting of seeds and for accurately conveying the seeds from the seed meter to the seed-bed to keep an equal seed-to-seed distance. An optoelectronic seed sensor inserted in the middle of a square seed tube can be seen in figure 2.

Figure 2: Seed Sensor and Seed Tube, DS1000i Seed Sensor by Digi-troll

This research proposes a multi-crop seed monitoring sensor, based on optoelectronics. The proposed seed sensor uses optical sensors and has multiple algorithms for the detection and counting of seeds of multiple crops. The data from the sensor is passed on to a microcontroller for further processing.

The manual method of seed planting over a large area consumes more time and results in low seed placement, non-uniform seed spacing, and low production. To mitigate the problems associated with the manual method of seed planting, planters equipped with seed metering units are used which distribute seeds uniformly at the desired application rates. To make such planters suitable for precision agriculture, there is a need for a Seed Sensing Module, which would help overcome excessive seed loss, detect and count single, double, and missing seeds, and determine the proper seed population.

Scope of The Study

This study is being undertaken for the design and development of a Seed Sensing Module made of a seed detection and counting sensor and a seed tube. The module will help transform a normal planter into a precision planter. The contribution of this study will be a physical prototype that can be integrated with a seed metering unit.

A Seed Sensor is a very important and crucial part of a Seed Metering Unit. It is responsible for accurately monitoring the seed quantity of multiple crops of seeds. Many seed sensors already exist but either they are expensive, need to be imported which are not suitable for seed planters made in Pakistan or there are some shortcomings in them like they can only detect seeds of only one type of crop. There are also many difficulties associated with the design and development of a multi-crop Seed Sensing Module, such as sensor and microcontroller selection, types of detectable crop seeds, seed counting algorithm, etc. This research work will be significant for the development of a solution to these problems.

II. LITERATURE REVIEW

Seed Sensors

As part of a larger research to monitor seed drill performance, Karimi et al. [9] discussed the viability of non-contact sensing approaches for detecting seed flow rate. They looked at using laser diodes (LD), infrared (IR), and light-dependent resistors (LDRs). They utilized light beams to estimate seed flow rates by designing and producing IR, LDR, and LD sensor devices, which detected seed shadows falling on receivers. Infrared (IR) detection was found to be the most consistent non-contact method of estimating seed flow rates across all tested units, with a strong linear connection (r = 0.87). The research recommended honing IR sensing for practical use in seed drills by developing a model for estimating mass flow and integrating it into existing operations.

Seed flow rate, ground speed, sowing rate, and real-time data presentation are the primary concerns of the research undertaken by Besharatia et al [10]. The authors point out that there has been surprisingly little study on measuring the mass flow rate of dispersed seeds and emphasize the innovative nature of their approach in the context of sowing rather than individual seed placement. The authors' system successfully implements the integration of seed flow sensors on individual seed tubes, revealing both the flow rate and the presence of the seed. They computed sowing rates per unit area by factoring in ground speed and mass flow rate, which improved the precision of the planting process. The research provides a realistic application of the monitoring system by including ultrasonic sensors to track seed and fertilizer quantities.

Zhai et al. [11] present a unique control mechanism to improve precision sowing in their research. Direct seeders, solve problems with the standard ground wheel-driven seed metering systems. The proposed system keeps the rotational speed of the seed-metering device and the seeder's operational pace in sync with the help of a Hall sensor, microcomputer system, motor control module, stepper motor, and display. To do this, the seeder's current status, seed spacing, and planned sowing rate are used to calculate the optimal speed for the seed-metering mechanism. The method successfully corrects the unpredictability of ground wheel slippage to improve seed distribution. The effectiveness and dependability of the technique to achieve greater consistency in seed dispersal have been verified by experimental verification. This novel method has the potential to improve precision seeding by solving problems associated with both seed-metering devices and planters.

D. L. Okopnik et al. [12] conducted research to find a solution to the problem of automating the seed-detecting processes involved in plant ability tests. Together with a microprocessor, they unveiled the infrared sensor DFRobot RB-DFR-49 for measuring the space between individual seeds. High precision was shown in the analysis of maize seeds, with a slope in the linear adjustment of 1.03 and a correlation coefficient of 0.9998. In a full test using 45 seeds, the sensor showed a standard variation in distance readings of only 1.9 mm on average. Furthermore, over 96.5% of 1000 maize seeds were recognized by the sensor, validating its potential for accurate seed recognition in automated settings.

Kong et al. [13] present a near-infrared hyperspectral imaging method for sorting rice seed varieties. Spectral data between 1,039 nm and 1,612 nm is analyzed using state-of-the-art classification techniques such as PLS-DA, SIMCA, KNN, SVM, and RF to inform model development. Particularly, SIMCA, SVM, and RF all achieve 100% accuracy on both the calibration and prediction sets, while PLS-DA and KNN both obtain above 80% accuracy. Model accuracy is improved by identifying ideal wavelengths, and models built on these wavelengths achieve classification rates of over 80%. This study sheds light on the utility of hyperspectral imaging for rice seed identification and the performance of the RF algorithm in classification, paving the way for more refined seed classification and optimized yields through the application of precision agricultural techniques.

Mortensen et al. [14] emphasize the urgent need for improved seed quality evaluation methods. The authors highlight the industry-wide demand for more efficient and cost-effective methods by stressing the importance of high varietal identity, purity, germination capacity, and seed health. Multispectral imaging (MSI) and near-infrared spectroscopy (NIRS) are two non-destructive techniques that have shown promise in recent years for use in seed research and the seed industry, and these techniques are discussed in this study. The authors provide insights into the benefits and limitations of integrating MSI and NIRS to produce speedy and precise seed testing outcomes by exploring applications spanning physical and physiological seed quality and seed health evaluation.

Scotford et al. [15] tested winter wheat growth with a two-channel radiometer system and an ultrasonic sensor on a tractor-mounted boom. In a replicated trial, three winter wheat types (Claire, Consort, and Riband) were planted at different seed rates (50, 150, and 250 kg ha−1) in 27 plots. The researchers assessed canopy expansion and senescence using NDVI at 660 and 730 nm. However, the ultrasonic sensor monitored crop height and density. They found that NDVI accurately reflected the canopy expansion and senescence curve for winter wheat, helping monitor crop growth until the first node observable stage (GS 31). The ultrasonic sensor was best for tracking crop growth beyond GS 30, which indicates early stem elongation. Ultrasonic data revealed crop density, notably before mid-booting (GS 45). The study showed that radiometers and ultrasonic sensors can work together to analyze crops throughout the growth season. The results showed that ultrasonic density and NDVI measurements before GS 31 could reveal crop cover and canopy features. This study establishes the basis for using radiometers and ultrasonic sensors to accurately monitor winter wheat development dynamics.

Precision Planting

In [16], Yanxin *et al.* propose a precision planting maize monitoring system. In particular, the design and testing methodology for photoelectric cell-based seeding rate sensors was investigated. The approach calls for the creation of a seed monitoring sensor based on an opposite-type infrared photoelectric cell as well as the development of an estimation model for the number of photoelectric cells and the layout characteristics of those cells. The sensor demonstrated exceptional precision and accuracy in a series of tests conducted both in a lab environment and outdoors. A more precise planting operation will be possible thanks to the maize monitoring system, which offers a dependable and stable solution for online evaluation of the success of maize planting in real time.

For the electric seeder of small-size vegetable seeds, a boot-style furrow opener, a rear press wheel, and a driving motor were invented by Xin Jin *et al.* [17]. The sowing wheel was created in a variety of diameters and sizes to fulfill the demand for varied seed sowing sizes. Precision sowing, real-time monitoring of sowing quality, and simultaneous repression, sowing, and furrowing are all capabilities of the electric small-grain vegetable seeder and sowing monitoring system. The findings revealed that radishes, Chinese cabbage, and carrots all have above 94% accurate seeding rates. Interference can be effectively suppressed by the system's monitoring.

To increase the effectiveness of the seed metering unit operation, a laser-based air-suction precision device was developed by Jian Xu *et al.* [18]. The pneumatic seed metering unit's primary design goal was to increase the consistency of high-speed direct seeding of plants. Seeding impact with the modification of the field of low on various hole sizes was examined using the coupling method. The relevant experimental indicators i.e., qualified, multiple, and missing indexes were found by verification studies. They were found to be 95.9% qualified index, 1.2% multiple indices, and 2.9% missing index.

To address problems such as subpar poor planting quality and low-speed restrictions associated with the traditional chain-driven and ground wheel planters, D. Zhang *et al.* [19] present a control system design for a motor-driven seed metering unit of a precision planter. A closed-loop proportional-integral-derivative (PID) was implemented for the rotational speed of the seed plate. For an average traveling speed of 8.6 km/h, the values for QFI, MI, and PREC were 98.6 percent, 1.29 percent, and 14.5 percent, respectively. The average value of QFI still managed to obtain 97.09 at a high traveling speed of 13.0 km/h. The system costs were significantly low compared to the same systems imported from abroad.

Anil Cay *et al.* [20] created an electro-mechanic drive system (EMDS) for the seed metering of a traditional single seed planter. Ten different seed spacings (z) ranging from 6-29.3 cm and three different operation speeds (v) were evaluated in a lab to compare the performance of EMDS with the conventional drive system (CDS). Regarding the consistency of seed spacing, both techniques were compared. During the tests on the EMDS, the values of the qualified feed index (QFI), multiple indexes (MLI), missing index (MI), and precision index (PI) ranged from 2.91 to 95.36 percent, 0 to 1.73 percent, 4.45 to 97.09 percent, and 8.79 to 22.14 percent, respectively. During the tests on CDS, the values of performance indices ranged from 2.09 to 98.55 percent for QFI, 0 to 0.36 percent for (MLI), 1.09 to 97.91 percent for (MI) and 5.79 to 20.92 percent for (PI).

To enhance the efficiency of precision planters during planting, Yang Li *et al.* [21], designed a system powered by mechatronics. Two distinct driving systems can now be used simultaneously in a two-row pneumatic precision planter. During each neighboring plot, seed spacing assessment, the qualified feed index (QFI), missing index (MI), precision index (PI), and uniformity in seed spacing were examined. During each forward speed on no-tillage and rotary-tillage lands, the mechatronic driving system outperformed the mechanical driving system with an average 4.70 percent rise in QFI and a 3.54 percent drop in the MI. the fastest forward speed of 12 km/hm, the mechatronic driving system can lessen the impact of forwarding speed on QFI, missing index, and precision index.

III. RESEARCH METHODOLOGY

The Seed Sensing Module, used for the Seed Delivery Mechanism of a Seed Metering Unit in a precision planter is made of two parts i.e., Seed Sensor and Seed Tube. The Seed Sensor helps in the detection of the seeds while the tube helps in conveying the seeds from the meter to the seedbed while planting. The Seed Sensor will consist of a transmitter and a receiver. The data from the sensor will be transferred to the microcontroller for further processing. The control algorithm will read the data and then according to the logic confirm if a seed has passed or not. The output data will be displayed on the HMI. The general framework for the seed monitoring sensor is shown in Figure 3.

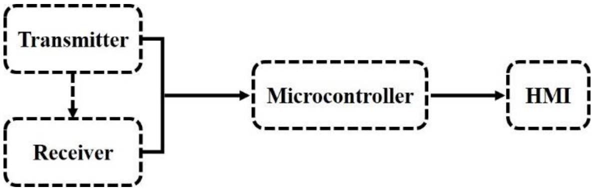

Figure 3: Framework for Seed Sensor

Because of their high accuracy and low cost, Optoelectronic sensors will be used as the Seed Sensor, in this study. The optical seed sensor will be integrated at the input of the seed tube, which will be placed at the opening of the seed metering unit. The falling seeds will pass in the middle of the tube for a high detection rate. To keep the costs low, a seed sensor based on a light-dependent resistor (LDR) and light-emitting diode (LED) will be developed. LDR and LEDs are suitable to use inside the Seed Meter because of their smaller size and easier control of input/output signal. The seed tube will be fabricated using a 3D printer for easy manufacturing and rapid prototyping. The seed tube will also help in holding and aligning the LEDs and LDR for proper detection of falling seeds. The overview of the Seed Sensing Module is shown in Figure 4.

The Seed Sensor will be controlled using an Arduino-based microcontroller. As LDR is a light-dependent resistor which means it changes its resistance with an increase or decrease in light. This means that the output from the sensor will be in analog form. A threshold in this analogue data range will be set in the microcontroller which will act as a base for the detection of the seeds. When the light is blocked in the tube, LDR changes its output which is continuously inputted to the microcontroller. Based on this data the microcontroller decides if a seed has passed or not. This helps in the detection and counting of seeds.

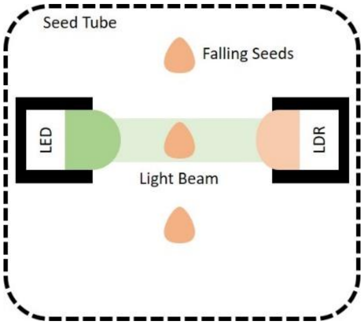

Figure 4: The Seed Sensing Module Overview

For the detection and counting of missed and double seeds, there is another variable in the system which is the time between the detection of two consecutive seeds. When this time is greater than the set range this means that there is a missed seed and it is counted. When this time is less than the set range this means that there is a double seed which is also counted. This data is then continuously fed to the HMI for reading.

The flow chart of the research methodology can be viewed in Figure 5. The flow chart outlines the different phases of the research work.

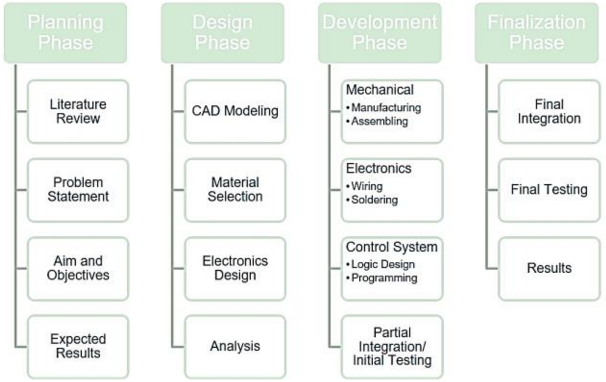

Figure 5: Research Methodology Flowchart

3.2.4. Exploded View

In this research, the LDR Casing, LED Casing, and Tube Casing were carefully designed. The LDR Casing protects and positions the light-dependent resistors (LDRs) for accurate seed detection. In the meantime, the LED Casing protects and aligns the light-emitting diodes (LEDs) that are an integral component of our optical seed sensing system. The Tube Casing, an indispensable component, contains both the LDR and LED enclosures in a single unit. It functions as a conduit for seed transport and incorporates optical components for precise seed detection. When coupled, these casings form a cohesive Seed Sensing Module that monitors seed passage efficiently. This integrated design demonstrates the synergy of these components in the magnified view, highlighting their critical role in achieving precise seed detection and seamless seed placement.

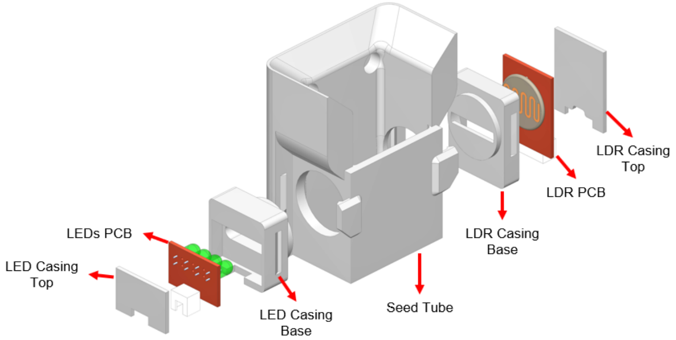

Figure 6: Exploded View

3.3. Electronics system: Architecture

The Seed Sensing Module's electrical system architecture detects seeds in precision planters seamlessly and precisely. Start with the power supply unit, which provides stable electrical energy to the system. A Buck Converter efficiently adjusts voltage levels to match the system needs to optimize and regulate this power supply. A voltage regulator attached to the Buck Converter stabilizes the power supply output, ensuring the system's sensitive electrical components' dependable operation.

The system works because light-dependent resistors (LDRs) and light-emitting diodes (LEDs) are strategically placed in front of each other. This optical detection arrangement is essential for precise seed detection by monitoring light intensity variations in the optical route. The ADS1115 Analog-to-Digital Converter efficiently converts LDR and LED analog impulses into digital data. Digitization is essential for data processing and analysis.

The Digi-spart ATtiny85 microcontroller runs the system. It analyses digital data from the ADS1115 and makes real-time choices based on seed detection as the central control unit. It also controls the Seed Sensing Module operation.

UART (Universal Asynchronous Receiver-Transmitter) connectivity allows the ATtiny85 microcontroller to share data and monitor laptops in real-time. This allows seamless seed identification data transmission to external devices, delivering vital precision agricultural insights. This comprehensive electronic system design detects and monitors seeds in the precision planter reliably, accurately, and efficiently, improving agricultural practices and crop output optimization.

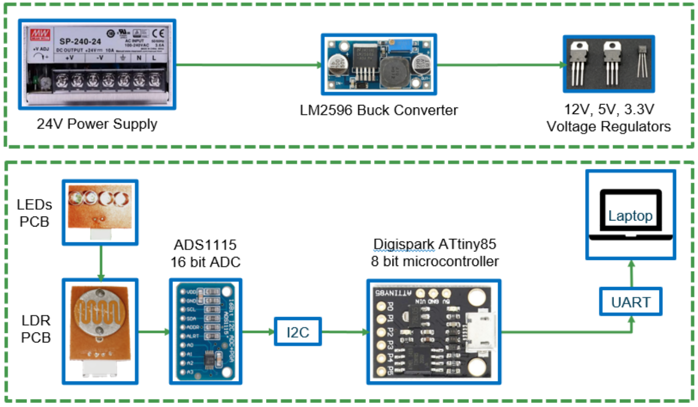

Figure 7: Electronics System Control Architecture

Schematic Design

A detailed and comprehensive visual representation of the design of the electronic system may be seen in the schematic for the Seed Sensing Module. In this diagram, several components, such as light-dependent resistors (LDRs), light-emitting diodes (LEDs), an ADS1115 Analog-to-Digital Converter, a microcontroller (ATtiny85), a voltage regulator, and a power supply unit, are arranged symbolically and connected. This diagram illustrates the precise electrical connections and signal pathways that are necessary for accurate seed detection. The schematic design plays a crucial part in defining the circuitry and the logical flow of data, which helps to provide a clear understanding of how the Seed Sensing Module operates at the electronic level. Ultimately, the schematic design serves as the foundation for the subsequent PCB layout design and the physical execution of the device.

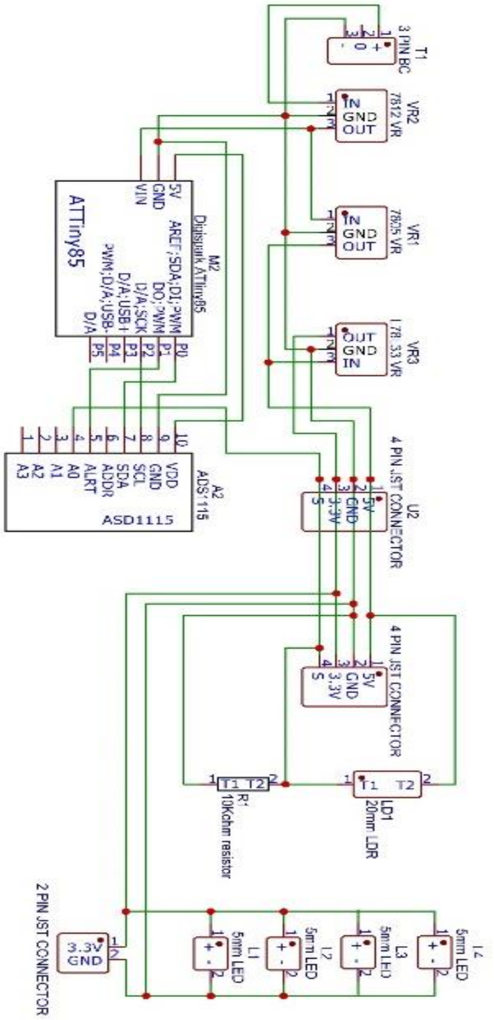

Figure 8: Schematic Design

PCB Design

The critical stage in the creation of the Seed Sensing Module is known as the PCB (Printed Circuit Board) design phase. This is the phase in which the electronic components of the schematic are transformed into a physical layout. To guarantee an error-free and effective functioning, this procedure requires accurate component placement, painstaking copper trace routing, and extensive design rule checks. On the printed circuit board (PCB), the essential electrical connections are formed by components such as LEDs, LDRs, the ADS1115 ADC, an ATtiny85 microcontroller, a voltage regulator, and the power supply unit. These components are organized strategically. The printed circuit board that was produced as a result now acts as the central hub for the Seed Sensing Module. This makes it possible for the precision planter to perform accurate seed detection and data processing, which eventually contributes to the development of precision agriculture.

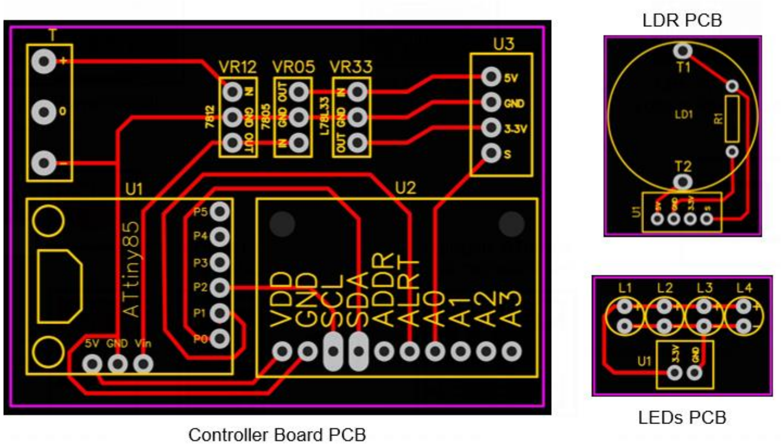

Figure 9: PCB Design in Easy EDA

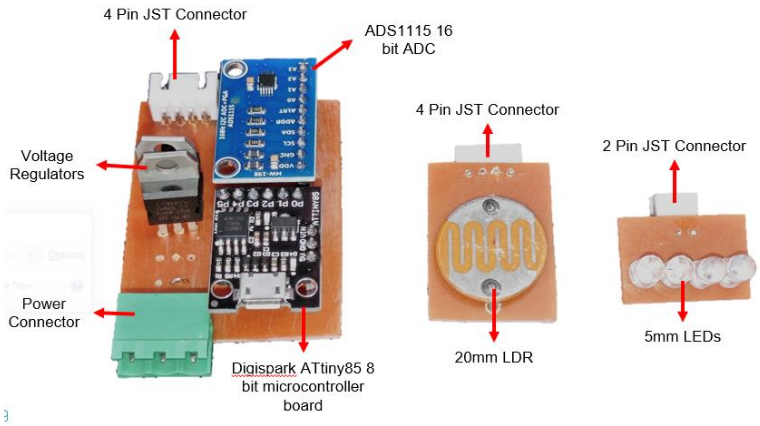

Figure 10: PCB Fabricated

Control Framework

When performing tasks related to precision agriculture, the control framework that is responsible for coordinating the functioning of the Seed Sensing Module is an essential component that ensures correct seed detection and counting. The emitter starts the process by sending out a signal, which is often light, that interacts with seeds as they go through its route. The receiver then detects changes in this signal when seeds are present and determines whether or not the process was successful. Whenever the microcontroller recognizes the presence of a seed, it immediately assumes control and employs decision logic to partition the data into three distinct categories. In Case 1, the single seed counter is incremented when a single seed is found to be within a limited tolerance range close to the expected period. This causes the case to be considered a success. Case 2 is activated when there is no seed found within a larger tolerance, which causes an increase in the miss/skip seed counter. Case 2 is triggered when there is no seed found. Case 3 acknowledges the detection of multiple seeds within an extended tolerance range, which suggests the presence of double or multiple seeds and causes an increment in the double/multi-seed counter. Lastly, Case 3 acknowledges the detection of multiple seeds within an extended tolerance range. During the process of precision planting, this all-encompassing control framework plays a critical role in supporting precise seed monitoring, enabling accurate seed counting, and identifying instances of missed or multiple seeds, which ultimately contributes to an increase in the overall productivity and efficiency of agriculture.

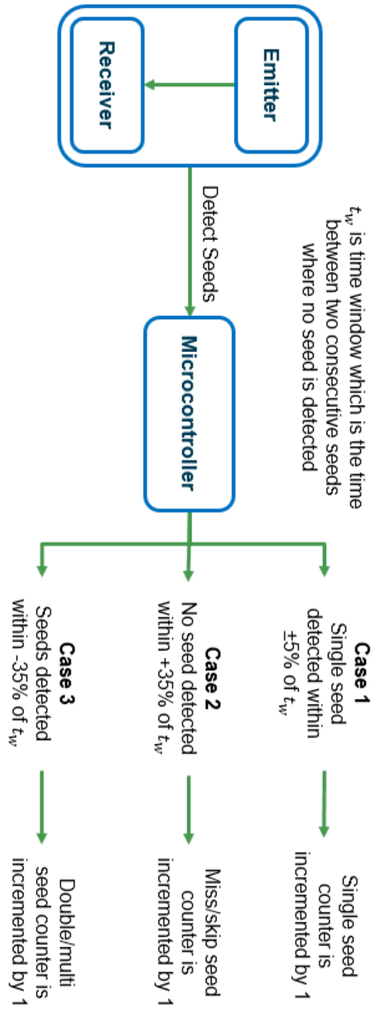

Figure 11: Control Framework

In this Section, we examined the Seed Sensing Module, a crucial part of a precision planter's Seed Metering Unit's Seed Delivery Mechanism. This module uses the Seed Sensor and Seed Tube to accurately detect and transport seeds during planting. The Seed Sensor uses LDRs and LEDs to detect seeds and provide data to a microcontroller. A complex control algorithm drives this microcontroller to evaluate seed passage and record outcomes. The efficient 3D-printed Seed Tube helps align sensors, carry seeds, and detect precisely. Without discussing HMI, we have examined the electronic system architecture, mechanical design, and control framework, which improve seed detection, counting, and monitoring in precision agriculture.

IV. TESTING AND RESULTS

Objective of Testing

The main aim of this study is to evaluate the efficacy of the Seed Sensing Module in precisely detecting and quantifying seeds as they traverse through the device. This assessment aids in determining if the module achieves the intended degree of precision and dependability in seed enumeration. The objective of this experiment is to assess the impact of varied disk speeds (15 RPM, 20 RPM, and 25 RPM) on the performance of the sensor module. The significance of this matter lies in the fact that agricultural machinery has the potential to function at varying speeds when in the field. Consequently, the sensor must yield consistent outcomes even when confronted with such diverse settings. The utilization of manual counting and visual examination is employed as a standard measure to validate the precision of the Seed Sensing Module. The objective is to conduct a comparative analysis between the counts generated by the sensor and those obtained manually by humans, to detect any inconsistencies or inaccuracies. This process is crucial to verify the accuracy of the seed counting module. The objective of conducting data analysis is to produce quantifiable outcomes that effectively demonstrate the sensor's performance concerning accuracy, precision, and consistency. This study facilitates the identification of potential areas that may require modification or change in the design or functioning of the sensor.

Equipment

The Seed Sensing Module (SMU), Seed Metering Unit (SMU Integration), Testing Rig or Platform, Suction Motor, Power Supply, a microcontroller, a disk speed control system, light emitting diodes (LEDs), light-dependent resistors (LDRs), a data logger, a computing device, and several measurement instruments.

Testing Procedure

1. The first phase entails the establishment of the Seed Sensing Module (SMU) and the configuration of the testing rig to ensure the readiness of all components for the forthcoming testing protocols. This entails safely installing the SMU within the rig and ensuring that the microcontroller is correctly programmed for data gathering and control.
2. To uphold uniformity and precision during the testing procedure, a total of 100 maize seeds are carefully collected, with thorough attention given to their cleanliness and freedom from any impurities, soil particles, or extraneous substances that may potentially impact the outcomes of the experiment. The aforementioned selection process guarantees that the seeds are in their ideal condition for testing.
3. The operational speed of the Seed Metering Unit is deliberately configured to a specific and accurate rate of 15 revolutions per minute (RPM) during the initial trial. The calibrated speed will function as the manipulated variable during experimentation,

enabling the assessment of the performance of the SMU under predetermined circumstances.

4. The testing apparatus is activated to commence the testing procedure. Activation involves the initiation of the Seed Sensing Module (SMU) and the corresponding suction motor, which plays a vital role in the movement of seeds within the Seed Metering Unit.
5. A collection including 100 uncontaminated maize seeds is permitted to pass through the Seed Metering Unit. During the trial, the Seed Sensing Module is responsible for counting and documenting the number of seeds as they traverse through the system.
6. The Seed Sensing Module correctly records and documents the seed count as an integral component of the trial data collection process. The aforementioned recorded count plays a crucial role as a primary data point in the assessment of SMU's performance.
7. Concurrently with the seed counting procedure employed by SMU, a separate manual count of the 100 corn seeds is performed. The purpose of conducting a manual count is to produce a benchmark figure that serves as a point of reference for evaluating the performance of the SMU. This practice is essential for verifying the precision and reliability of the seed-counting process.
8. A comprehensive examination of the seed flow is conducted to detect any possible anomalies, such as occurrences of duplicate seeds or omitted seeds that could potentially impact the overall precision of the seed enumeration procedure.
9. To conduct a full evaluation of the performance of the SMU, the testing technique is rigorously replicated at two additional rotational speeds of the disk, specifically 20 RPM and 25 RPM. The act of repeating enables a comprehensive assessment of the SMU across different operational circumstances.
10. After each trial, the seed counts collected from the Seed Sensing Module are carefully examined and compared to the counts obtained manually. This comparative analysis facilitates an evaluation of the accuracy and precision of the Seed Measurement Unit (SMU) in seed counting.
11. The trial outcomes, encompassing seed counts, any observed disparities, and other pertinent observations, are meticulously recorded for every trial. The aforementioned records offer significant insights into the performance of the SMU across various disk speeds.
12. Conclusions about the performance of the Seed Sensing Module are derived based on the study of the data. If deemed required, suggestions for enhancements or modifications to improve the precision and dependability of the module are developed, thereby contributing to the continuous evolution of the technology.

Data Analysis

The evaluation of the number of seed tubes in comparison to the observed count of 100 maize seeds is an essential component of quality assurance and precision agriculture in contemporary farming methodologies. This procedure aids in guaranteeing the precise delivery of the required quantity of seeds per row by the planting equipment, hence directly influencing crop production and the overall productivity of the farm. The measurement of the mean and standard deviation of seed tube count data yields significant information regarding the consistency and dependability of planting equipment. This, in turn, empowers farmers to make educated decisions aimed at optimizing their planting processes.

Mean

The mean, which is often referred to as the average, is a statistical measure of central tendency that offers insight into the average deviation of seed tube count from the actual count. To determine the mean: The mean is calculated by dividing the sum of the seed tube counts by the number of measurements. The mean value offers significant insights into the consistency of the planting equipment in terms of exceeding or falling short of the intended 100-seed count.

Standard Deviation

The standard deviation is a statistical measure that quantifies the extent of dispersion or variability observed in the data about the count of seed tubes. A larger standard deviation implies increased variability in the delivery of seeds. To compute the standard deviation: The formula for calculating the standard deviation is given by taking the square root of the sum of the squared differences between each measurement and the mean, divided by the number of measurements minus one.

Data Explanation

The Mean Seed Tube Count, which is estimated to be around 98.1, offers valuable information regarding the typical efficacy of the seed tube counting technique. This data indicates that, on average, the seed tube counting technique tends to significantly underestimate the actual seed count in comparison to the projected count of 100 seeds. Although there is a slight departure from the desired aim of 100 seeds, this deviation falls within the acceptable range of 98 percent accuracy. This suggests that, on average, the system is performing at an acceptable degree of precision. This implies that the equipment exhibits a generally dependable performance in dispensing seeds, albeit with a slight inclination towards underestimating the quantity. The assessment of the system's performance consistency heavily relies on the Standard Deviation of the Seed Tube Count data, which is roughly 1.04. The analysis of this parameter demonstrates that the seed tube counting system yields outcomes that exhibit minimal deviations from the computed average. Although there exists a persistent tendency to underestimate, the level of precision in these underestimations is consistently stable and falls below an acceptable threshold for attaining a 98 percent level of accuracy. The observed low standard deviation suggests that the measurements of the system are characterized by consistency and lack significant variability. This finding is encouraging as it implies that the system is capable of sustaining accurate and precise seed distribution.

In conclusion, the seed tube counting system is close to achieving a 98% accuracy rate in seed counting. The system slightly underestimates the seed count, but its precision is acceptable. The system's accuracy and consistency suggest it can reach 98 percent accuracy with little tweaks. However, the count method used in practice consistently measures 100 seeds with great precision, providing a standard for evaluating desired accuracy.

Table 1: Seed Counting

Trial	Seed Tube Counting	Actual Count	Single Seed	Double Seed
1	98	100	94	2
2	97	100	95	1
3	98	100	92	3
4	99	100	95	2
5	97	100	95	1
6	99	100	95	2
7	96	100	92	2
8	98	100	94	2
9	97	100	95	1
10	98	100	94	2

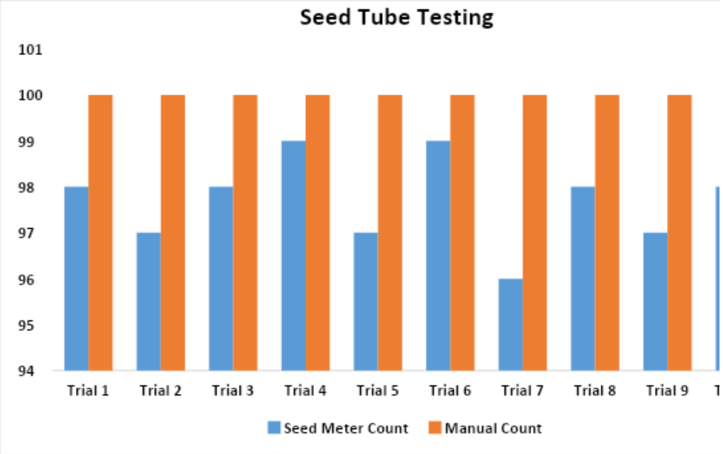

Figure 12: Seed Meter Count and Manual count

V. CONCLUSION

To summarize, this study presents an innovative Seed Sensing Module that enables precise seed counting and identification across a diverse range of agricultural crops. The gadget employs a Seed Tube that is created using 3D printing technology, along with optoelectronic sensors, within a well-organized electronic framework. This allows for the efficient processing and immediate transmission of data. The implemented control system effectively distinguishes between single, missed, and double seeds, representing a significant advancement in precision farming.

The testing findings have emphasized the crucial aspects that affect the accuracy of seed counting. The system now achieves a commendable accuracy rate of about 98%, and with some minor adjustments, it has the potential to become much more exact. Future research should focus on the calibration of sensors, guaranteeing seamless integration of hardware, and broadening the application of this technology. This study's innovative approach to agricultural methodology suggests that achieving higher efficiency and productivity in farming is attainable.

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