BUND DETECTION SYSTEM USING ULTRASONIC SENSORS: A REVIEW

Abstract

Optimum header height control system for combines minimises harvest losses, chances of equipment damage and operator fatigue. To control the header height of combine harvester the researcher used different mechanical and electronic systems. In mechanical systems, iron fingers are attached to the bottom of the cutter bar and a hydraulic system is used for sampling the ground profile and to detect any obstacle in the running path. Ultrasonic sensors, infrared sensors, and video-based predictions were used in electronic systems for controlling header height. Research data shows that vertical sensor orientation provides more accurate sensor-to-target readings as compared to horizontal sensor orientation. Ultrasonic sensors can perform better than Infrared sensors for tile, plastic, wood, or sponge types of obstacles. The accuracy of ultrasonic sensors was dependent on targetto-sensor distance and terrain type and independent of the speed of the machine. The ultrasonic sensor showed a maximum average error when the sensor's interference was analysed at 30 cm apart. A major limitation of the header control system was that it showed instability due to hydraulic actuator speed and crop conditions.

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I. INTRODUCTION

At the time of the Green Revolution, the combine harvester was introduced in India. Combines are used to carry out basic functions of crops harvesting such as cutting, collecting and feeding, separating, threshing, cleaning and crop handling (Chaab *et al* 2020). The total number of combine harvesters increased to over 40,000 from 800 during 1972-2016 (Singh *et al* 2020). Most of these combines have been manufactured by more than 48 manufacturers of Haryana and Punjab. On Indian farms, 900-1000 combines have been added every year. Initially, Western Uttar Pradesh, Haryana and Punjab were using combine harvester but nowadays, it has been used all across India due to several reasons like high wage rate, shortage of labour, weather uncertainty and unpredictability (Singh*et al* 2020).Combine harvester provides an efficient and fast way to perform crop reaping, separating, threshing and cleaning activities in a single operation. It consists of reel, header platform, crop divider, cutter bar, fan, grain sieves, platform auger, grain elevator, grain unloading auger, grain container, straw walkers, chaff sieves, feeder conveyer, grate and concave. There are many machine-based factors (like peripheral speeds, combine forward speed, cutting height, feeding rate etc.) that affect performance of combine harvester and crop loss. The total combine harvester loss has been divided into different types such as pre-harvest loss, header loss, cleaning loss, and threshing loss (Bawatharani *et al* 2014). According to Lopes *et al* (2002),80% of crop production loss occurs in the gathering and cutting processes which have been influenced by the cutter height. In support of this, Xie and Alleyne (2012) disclosed that 75% of crop loss occurs at the header during the harvesting process due to improper setting of the height of the header. In case, the height of the header is too larger, then this will decrease the total harvest yield (Xie and Alleyne 2012). On the other hand, if the height of the header has been set to very low, then this will touch to uneven terrain and soil bund that leads to operator fatigue and equipment damage. Further, field with many bunds cause more stoppage and wastage of time in taking turns affecting field capacity and fuel consumption of combine harvester (Sharanakumar *et al* 2011). There is a requirement to operate the combine carefully to minimize losses and overcome challenges associated with frequent breakdowns. To overcome header loss problem in an uneven field with many bunds, a desirable header height needs to be adjusted by the combine operator.A sensor-based soil bund detection system is required to operate the header of combine harvester at a desirable height to reduce the header loss, operator fatigue and fuel consumption. Ultrasonic, LiDAR and Infrared sensors are suitable for bund detection systems because these sensors detect the object without physical contact. But ultrasonic sensors provide better short-range distance measurement accuracy and are also operatable in dirty environment conditions (Abbas *et al* 2020). The ultrasonic sensor's working is based on the reflection of sound waves, Sensor’s transmitter emits sound waves, waves are reflected from objects, and the waves are received by the receiver of the sensor. By measuring the time difference between the emitted and received sound waves and knowing the speed of the sound in the air medium, the distance to an object can be estimated (Schirrmann *et al* 2017). Experiments and research works showed uses of various ultrasonic sensors in the field of agriculture. Leonard and Maki (1990) introduced the concept of an automatic Header Height Controller (HHC) to calculate distance between cutter bar and ground using ultrasonic sensor of Model 606191 Polaroid Corporation ultrasonic transceiver. In another study, UDS-10A ultrasonic sensors were utilized by Huh *et al* (2014) on a combine header frame for detecting cutting width. Zhang *et al* (2020) utilized two UKF1600-G18-VN7L-Q12 type ultrasonic sensors to design an intelligent control system to detect distance for maize picking harvest. Jeon and Zhu (2011) used LV-MaxSonar-WR1, USA, MN and Baxter ultrasonic sensors to develop a sprayer system to detect tree canopy. In another research work, Maghsoudi *et al* (2015) used three USS3 model ultrasonic sensors to estimate and detect dimensions of tree canopy for adjusting application rate. Studies has been conducted with ultrasonic sensors on agricultural machines for different purposes. Only a few studies have examined automated ultrasonic sensors-based header height control systems for combine harvesters. However, no study has been conducted for soil bund detection systems for controlling the header height of combine harvester. A soil bund detection system is considered an important parameter for reducing cutter bar damage, operator fatigue, and fuel consumption. Very limited work has been done on automated ultrasonic sensors-based header height control systems for combine harvesters in India. This study helped in generating information to develop a system model for actuating header of the combine harvester for the detection of soil bunds by ultrasonic sensors.

II. REVIEW OF LITERATURE

1. **Height Adjustment Systems for Header of Combine Harvester:** Leonard and Maki (1990) designed and developed an automatic height control system to calculate and control the distance between the ground and cutter bar on header, through ultrasonic sensors. The results showed that vertical sensor orientation provides more accurate sensor-to-target readings as compared to horizontal sensor orientation. It was found that the accuracy of ultrasonic sensors was dependent on target-to-sensor distance and terrain type but it was independent of the speed of machine. The major limitation of this header control system was that it showed instability due to transient windrower motion, hydraulic actuator speed and crop conditions.

   Xie *et al* (2010) utilized Linear Quadratic Regulator (LQR) developed a state feedback controller that could address a problem of header height control (HHC). In the design of LQR controller, cost function was defined using header vibration velocity and tracking error. A reduced states feedback controller system was developed that utilizes skyhook damper to simplify design of full state feedback controller. The results of simulation disclosed that reduced state feedback controller could reject disturbance and achieve better reference tracking with less feedback information.

   Musumeci (1983) focused on the problem of cutter height control encountered by sugarcane harvesters. The main attention was assumed to a pressure difference method to address the problem of base cutter control. Investigation techniques were used to analyse oil pressure drop across the hydraulic motor's base cutter. The physical and experimental system analysis indicated that pressure difference variances could be utilized as cutting height quantifiers. Exponential window and rectangular window estimators were two techniques considered to estimate variance. Findings disclosed that significant time delays should be introduced to make reliable and accurate height adjustments.

   Lopes *et al* (2002) developed an optimal HHC system for combines that can minimize operator fatigue, harvest losses and chances of equipment damage. To make adjustments in the header height, the on-off controller was incorporated in the combine harvester. To design an optimal and robust HHC system, LQG/LTR (Linear Quadratic Gaussian/Loop Transfer Recovery) was applied. The disturbance rejection capacity of the system was compared against the conventional on-off system to verify and test performance of the developed system. The research outcomes showed that utilization of the LQG/LTR controller would enhance system's disturbance rejection capacity. Along with this, usage of developed systems does not change the energy expenditure levels with regards to conventional on-off system. A necessary frequency range should be identified before designing and developing LQR/LTR controller because trade-off between noise rejection capacity and performance affects its overall working.

Liu *et al* (2019) designed a video-based prediction system in order to address the HHC problem of combine harvester. A crop presence classifier was used to predict the time when the reel of header should be lifted. A 2-step spatial segmentation approach was also designed to locate the region. Classifiers were trained on texture-based features to detect crop presence and estimate crop percentage. The trends of the presence of crop has been observed and analysed to predict and determine the time when the header should be lifted. The designed framework was tested on wheat and bean harvesting sequences. The proposed camera-based system could estimate the time when the header needs to be lifted but could not predict time to be at a lower position. The system only considers header height either low or high positions, the researchers suggested that future improvements could be achieved by predicting precise height positions.

Pan *et al* (2019) designed a Header Height Automatic Regulatory System by incorporating hydraulic automatic control technology and infrared sensing technology in header to accomplish self-adaption of header height of a combine. Hardware circuits of the proposed system were designed with the use of Altium Designer. The master controller of the system had single-chip micro-computer. In the designed system, infrared sensors were used to measure header height of combine harvester. The sensor captures value of header height from the ground and send the captured data to the micro-computer. When the header height was not appropriate then a signal has been sent to the micro-computer to fall or raise the header. The system was reliable as it could work on uneven surface. The system was economical as low-cost devices (like micro-computer, and infrared sensors) were used to design. System was considered economical by farmers for mass production.

Ni *et al* (2021) developed a header height adjustment system to address the problem of soil shoveling and poor harvesting of soybean plants. For current soybean harvester system, hydraulic driving system and a profiling mechanism were designed. Information about soil compactness of soybean plants was collected to construct a mathematical model. The results of conducted field harvesting experiment indicated that absolute error between profiling height and stubble height adjusted by IPC (Industrial Personal Computer) was less than 2mm before the tests. In 4 groups of tests, the variation coefficients of stubble height were 6.5%, 8.5%, 11.6% and 9.3% with respective 92%, 90%, 86% and 88% profiling control accuracy (Ni *et al* 2021). Based on results, soil compactness and ground flatness had minimal impacts on control system.

Jin *et al* (2018) designed a device for electronically adjusting the parameters of the combine harvester header for wheat and rice harvesting. The designed device controls the reel speed, reel height, reel position, and the header height of the combine harvester header. The device included sensors, Programmable Logic Controller (PLC) for the controller, a touch screen for data display, a hydraulic system for the header, and switch buttons. The sensors detect the signal and transfer it to the PLC unit which was the main device to control all the header parameters. Reel speed was automatically controlled by using a mathematical model and fuzzy PID (proportional integral derivative) algorithm. The parameter adjusting device for the header was mounted on the test prototype, and the regulatory tests, the data collection and the data analysis were performed. According to experimental results, header parameters could be electronically controlled. Relative adjustment errors of reel height, reel speed, reel position and header height were 3.4%, 7.8%, 2.0%, and 7.4% respectively. The response time of the designed system was less than 0.8 s and the adjustment time for the controlling was below 1.7 s. The designed system met the requirements for the header parameter control in a combine harvester.

2. **Sensor Systems Used In Combine Harvester:** Huh *et al* (2014) developed an ultrasonic cutting width sensor for multi-purpose, medium-sized, full-feed type combines that could monitor crop yield. The system was designed to target broadcasted and row planted rice, rapeseed, soybean, wheat and barley. Target combine has 1.7 m/s speed, 200 cm cutting width, and 1.5m turning radius. On the frame of combine header, 2 ultrasonic sensors were located that were further connected to the PC via USB port. The performance of the ultrasonic unit-based distance measuring system was verified by calculating distances to the wall. Correction formula calculation was applied to calculate the distance with wall and results showed that ultrasonic sensors could be used to measure distance in the actual crop because its maximum precision value was 98.9% with a 0.9656 cm average error. When the system was used to measure the distance of rice in a paused state, then the average and minimum accuracy was 98.6 and 97.7%, respectively. In another case, when the distance of rice was measured in a moving state, the minimum accuracy of system was 82.3%. The results concluded distance on crop has been measured through ultrasonic sensors for monitor crop yield.

Teng *et al* (2016) developed Laser Rangefinder (LF) based uncut crop edge detecting system for Yanmar AG1100 combine harvest. LF was primary sensor combined with an inertial measurement unit (IMU) and pan-tilt unit (PTU). The method of Otsu was preferred to detect the position of crop edge on the scanning profile. To adjust the crop edge line, the least squares approach was used. The validation experiments were performed in a wheat field under both dynamic and static conditions during harvesting season. The edge's real position was measured through GPS to verify and evaluate the accuracy of the proposed system. The experiment results presented an average lateral error of ±25 cm for the dynamic test with 10.15 cm Root-Mean-Square-Error (RMSE) and average lateral error ±12 cm with 3.01 RMSE. The performance of LR based edge detecting system was satisfactory under different field conditions.

Mirmahdiand Shirazi (2021) utilized two sensors viz. infra red sensor and ocular sensor on combine harvestorto address hazards, life risks, or unpredictable damages caused by wrong height control and the inability of the operator to detect objects like animals and humans. An infrared sensor was installed on the combine to detect objects to achieve zero life risk in the field. The ocular sensor was mounted on the combine to control height. The infrared sensor could minimize life risks to zero and ocular sensor adjusted the height of the combine automatically by observing soil composition. Sensors start alarming if they sensed a rock on the ground or combine hitting any object. The sensor-based height control and object recognition were found out to be good solution to minimize losses and achieve progress in the agriculture sector.

The feeding quantity refered to an important operating indicator for the combine harvester. By obtaining accurate information about the feeding quantity, a reliable monitoring system allows the driver to understand the harvest performance in real-time. It improved the combine harvester's efficiency and effectively reduced header and drum blockages caused by excessive feeding. Jiang *et al* (2022) designed and evaluated a system for combine harvester which was monitoring the feeding quantity based on variation in torque of the power input shaft. To improve the accuracy of signal processing and reduce the error of the torque-feeding quantity relationship, wavelet transform and support vector machine methods were used. The system and data processing methods used to monitor variations in feeding quantity were accurate and stable. Compared to previous studies, the results of the study showed that there was a lower deviation in feeding quantity measured by the system. Results also concluded that the feeding quantity measured by the developed system and actual data showed the variation of torque because of the uniformity of crop growth and the consistency of harvester operators.

Sirikun *et al* (2021) developed a system for sensing and monitoring grain yield for combine harvesters. This system also mapped the position and navigation, real-time grain mass flow rate and moisture content of grain of combine harvester. A computer with installed customized software which controlled a yield meter and GNSS receiver attached with the system. Grain yield maps were created using ArcGIS® software. The grain yields on the three fields averaged 3.63, 3.84, and 3.60 t/ha, and the grain moisture contents (w.b.) were 22.42%, 23.50%, and 24.71%, respectively. A grain yield of 3.84 t/ha (CV = 64.68%) was observed, with minimum values of 578.10 and maximum values of 7761.58 kg/ha, respectively. The coefficients of variation of the grain yields for the three fields were 57.44%, 63.68%, and 60.41. Various cutter bar heights were used in the test (0.18, 0.25, 0.35, and 0.40 m). The cutter bar height 0.40 m, has the least error in yield estimation of 12.50%. It was found that the developed grain yield sensor worked well with the local rice combine harvester.

Singh (2013) evaluated a grain yield monitoring system for a combine harvester. Using a yield sensor, GPS, and field computer with custom software, this system enabled real-time crop yield mapping, along with moisture data. The yield of rice grains was measured on the paddles of an elevator by using the light emitter and receiver of the optical sensor. Three fields consisting of 0.3, 0.22, and 0.32 ha were harvested by using a harvester fitted with yield monitor and moisture sensor. Throughout the three fields (1, 2 and 3), yields averaged 4,325.91, 5,093.14 and 4,287.66 kg/ha, respectively, with moisture contents of 21.42%, 22.78% and 20.42%. For all three fields, the coefficients of variation were on average 30.59%, 40.80%, and 40.39%. There was an average yield of 4,287.66 kg/ha with a 37.26% coefficient of variation across all fields harvested, ranging from 577.08 kg/ha to 7,661.48 kg/ha.

3. **Ultrasonic Sensors Used In Agriculture Machinery:** Singh (1982) used a polaroid ultrasonic sensor to develop depth-sensing unit that could calculate depth of tillage practice. Under simulated ground conditions with ±3 mm accuracy, the functioning of depth sensor was tested. Depth sensor was tested on different ground surfaces, linear

regression was used for determining relationship between simulated tillage depth and output voltage. The practical applications of depth sensor were verified by analysing key impacts of stubble ground cover, tractor noise, transducer tilt, and dust. Sensor performed well in all conditions except on stubble ground cover.

Chemical application of pesticides and nutrients in agricultural process resulted in harmful environmental damage, and labour hazards. Intelligent control systems based on variable rate spray systems used to ensure efficient and minimal use of pesticides. Variable-rate spray system enabled farmers to spray pesticides on the target in the right amount on the plant's canopy phase, season and canopy size. Abbas *et al* (2020) reviewed and presented different types of target detection spray systems that could detect geometric properties of plants. The laser scanners and machine vision systems were used for obtaining 3D maps and images of canopies and plants. Due to the limited utilization of sensors and uncontrolled environment in agriculture, some technical challenges were made in automation like lighting conditions that pose critical difficulties for spectral and machine vision analysis applications.

Table 1: Lidar, Ultrasonic and infrared sensors comparison

Characteristics/Sensors	LIDAR	Ultrasonic	Infrared
Range measurement: < 2 m	-	✓✓	✓
Range measurement: 30 - 100 m	✓	X	✓
Angle measurement: < 10°	✓✓	-	✓✓
Angular Resolution	✓✓	-	✓✓
Direct Velocity Information	X	-	X
Operation in the Rain	-	-	-
Operation in Fog or Snow	-	✓	-
Operation if there is Dirt on the Sensor	-	✓✓	X
Night Vision	N.a.	N.a.	✓✓

X impossible; - possible, but drawbacks; ✓✓ ideally suitable; ✓ good performance; N.a. not applicable;

Tewari *et al* (2018) developed a cost-expensive, tractor-operated ultrasonic sensor-based automated spraying system that can be used to detect plant canopy and spray liquid chemicals on the canopy. Sensing technology and Programmed Atmega328P was programmed properly to ensure automatic spray control via nozzles, pumps and solenoid valves. The developed sprayer was tested and evaluated rigorously in different modes by the researchers using 2 types of nozzles. It was found that the tilt and adjustable boom of nozzles enhanced the overall efficacy and effectiveness of spraying. The developed sprayer system has meaningful impacts on spray penetration, coverage, and minimal fruit infection. The Turbo nozzle was better than hollow cone nozzle as less affected by wind which leads to efficient spraying. Fruit infection was prevented by 95.64% using turbo nozzle. The developed technology was beneficial for better fruit production and pesticide saving in small orchards.

In Escola *et al* (2011), the ultrasonic sensor was used to measure the distance between the sensor and the tree canopy in order to calculate the apple tree canopy. A Sonar Bero PXS400 M30 K3 ultrasonic sensor was selected for the experiment. One PAC (Programmable Automation Controller – compactFieldPoint 2120) was used in Laboratory and field conditions to analyze the performance of the sensor. LabVIEW software was used to operate the PAC device from a laptop. The whole system was mounted on a vertical mobile platform. Under laboratory conditions ultrasonic sensor produced an average error of 0.53 cm in measuring distance. The accuracy of the sensor was reduced in the field and average error increased to ±5.11 cm due to variability in field conditions. The sensor showed ±17.46 cm average error when the sensor's interference was analyzed at 30 cm apart. At 60 cm apart, results showed that the average error was reduced to ±9.29 cm. These results showed that the tree canopy was accurately measurable when sensors were at 60 cm apart.

Li *et al* (2020) conducted studies to apply the chemical agents effectively to the crop canopy using an ultrasonic sensor adopting the ISODATA (Iterative Self-Organizing Data Analysis Technique Algorithm). Ultrasonic sensor KS109 (Guide Electromechanical Technology Co. Ltd., Shenzhen, China) was used to recognize the crop canopy. Based on fuzzy clustering, the algorithm adjusts the number and centre of clusters dynamically based on the structural characteristics of the crop canopy to achieve the best possible results. Potted corn plants with 3 to 6 leaf stages were examined on an experiment bench. In 3 leaf stage potted corn plant, the sensor showed maximum error. Based on the results, the ultrasonic sensor had a lower sampling rate and its calculated error value decreased with increased plant growth and increased with an increase in movement speed.

For precisely variable spraying, a system needs that accurately detected the characteristics of the canopy such as crop canopy density, volume, and thickness. The researcher found that the echo time interval of the ultrasonic sensor made a relation with the thickness of the canopy**.** Zhou *et al* (2021) use the Maxbotix MB7092-101 ultrasonic sensor for measuring the thickness of the canopy. A simulated canopy was used to conduct the laboratory experiment. Results showed that approximately 8.8% of the simulated canopy thickness differs from the actual canopy thickness. The same experiment was conducted in the field on the three Osmanthus trees which showed relative errors of 18.8%, 19.2%, and 19.4% respectively to the trees. Level of ground, distribution of tree branches, and canopy thickness measurement accuracy are the main reasons for higher relative error in the field than in the laboratory.

Adarsh *et al* (2016) compared performance of ultrasonic and infrared sensors for detecting different types of obstacles such as cardboard, paper sheet, wood, plastic, sponge, tile and rubber in robot navigation applications. For capturing distance parameters, the designed vehicle model was integrated with sensors and moved towards different kinds of obstacles. The outcomes of performed correlation analysis showed that ultrasonic sensors can better perform for tile, plastic, wood or sponge types of obstacles whereas infrared sensor can perform well for paper-sheet type obstacle only. In addition, rubber and cardboard types of obstacles could be detected with the combined use of infrared and ultrasonic sensors. The performed analysis was very useful for choosing the most suitable sensor for obstacle detection problems.

The concept of smart farming could be utilized to produce better yields by using the required amount of water especially in areas where water is not available adequately for farming. Garudand Mane (2019) investigated the use of advanced information technologies like Wireless Sensor Networks (WSN), the internet of things, etc. to achieve effective irrigation control. The technologies could measure the actual water requirements of plants that will be useful in producing better yields with limited water usage. NC-RUS ultrasonic technology used to sense leaves of different plant species for water content. With the help of the NC-RUS system, valuable information about turgor pressure and water content in the leaves could be captured. WSN technology has been utilized to trace and detect pipeline leaves in forest farming and hill station areas.

Bronson *et al* (2020) investigated and confirmed the utility of commercial, high-frequency and rapid-response ultrasonic sensors that can be utilized to estimate the height of cotton field crop. In the research work, researchers compared ultrasonic sensor measurements and manual plant height measurements in subsurface drip-irrigated cotton and also analyzed the effects of water management and nitrogen. Two Honeywell 943 ultrasonic sensors were utilized to measure canopy height in a water management weekly from 2016 to 2018 in Maricopa, USA. The results presented that ultrasonic-sensed-based plant height measurement is more accurate than manual height measurement. Thus, an ultrasonic sensor has the potential to measure the canopy height of the cotton plant. Further research is required to investigate whether the ultrasonic sensor can work to measure the height of wheat or other narrow-leaf crops.

Agricultural product classification and sorting is a major challenge for the agriculture industry that affects product quality. Advanced technologies and techniques can improve the efficiency of product classification in the agriculture industry. Beyaz & Gerdan (2020) implemented and tested the use of ultrasonic measurement techniques to efficiently classify different sizes of potatoes. LabVIEW platform was used to develop software used for classifying potatoes using ultrasonic sensors. As per regression coefficient outcomes, the regression between static ultrasonic sensor length measurement (SUL) and caliper length measurement (CL) is 95.5%, the regression between dynamic ultrasonic sensor length measurement (DUL) and CL is 86.9% and the regression between DUL and SUL is 87.9% for the classification of potato. These results proved that the ultrasonic sensor-based classification technique works efficiently and fast.

Wang *et al* (2021) introduced current progress and status of research on the structure, follow-up control and vibration of rape harvester header. The rape header should be equipped properly with the vertical splitting cutter in addition to the main reel, cutter and screw conveyor to address the problem of cross-linking and dense branches of rapeseed. This method helps to minimize the loss of shattering. Through the reasonable configuration of the rape header’s structure and optimization of its working parameters, power consumption and vibration of the header can be minimized and performance will be enhanced. The double-disc cutter of the header has low vibration and high cutting efficiency but this is very easy to be blocked and entangled. Thus there is a very high risk of failure. In the future, various kinds of crop cutters like circular chain cutters and multi-disc cutters can be developed based on the research status of the main header cutter.

For corn plant height monitoring, Latifah *et al* (2020) used the ultrasonic sensor. Before this study, two methods were used to measure the plant height; one was manually, and the second was by documenting human resource data. In both cases, there was always the problem of providing data manually, which was less accurate and time-consuming. So this system solves problems by using technology. An ultrasonic sensor was used to measure the corn plant height. The Raspberry Pi microcontroller was used to control the ultrasonic sensor. Resparry Pi transferred collected data by using the LAN (Local Area Network). The range of operation was between 5 and 115 meters because beyond this range, network connectivity failed. Results of the study show that the error percentage in height measuring of the system was 9.6%.

Swain *et al* (2009) developed a bare-spot and weed-detecting system for the wild blueberry. Bare spots and weeds reduce farm profitability and increase environmental risks. To detect weed and bare spots, ultrasonic sensors were used, which was low in cost. The sensor was mounted on the rear wheel of the farm vehicle. Trimble Ag GPS 332, which was mounted above the sensor, was used to map sensor data points. To store the sensor and coordinate data, a custom software interface was made in Lab View 8.5. Calibration was done by comparing sensor readings with fixed object heights in the lab and vegetation in the field. 0.54 m/s Speed was maintained to survey the field's bare spots and weeds. The result showed that R^2 came to 0.98, which shows the significant relationship between the sensor and actual readings.

Dvorak *et al* (2016) used the ultrasonic sensor to detect the object for the construction and agricultural Environments. Ultrasonic sensors were tested for their accuracy to detect a variety of items that are commonly found on construction sites or in the Agricultural field. The sensor was tested on a sheet of OSB (oriented strand board), a human body dummy, a wooden post, a water jug, and a plant Dracaena. Distance from the sensor to the target was in the range of 1 to 300 cm for each object. This Study's results showed that the ultrasonic sensor on a softer surface object showed less accuracy and sometimes not detected the target.Yuan *et al* (2018) used LiDAR (light detection and ranging) and ultrasonic sensors devices to develop a ground-based multisensor phenotyping system. In the phenotyping system, one LiDAR sensor (VLP-16 Puck, Velodyne LiDAR Inc., San Jose, CA, USA) and three ultrasonic sensors (ToughSonic 14, Senix Corporation, Hinesburg, VT, USA) were used.

An unmanned aerial vehicle (UAV) was equipped with a Zenmuse X5R RGB camera (DJI, Shenzhen, China). By using a ground phenotyping system and a UAS (unmanned aircraft system), 100 wheat plots were measured five times and the sensors data was compared with the manual height measurement data. The LiDAR provided the best performance, with an R^2 of 0.97 and RMSE of 0.05 m. From UAV, reasonable results were obtained with an R^2 of 0.91 and an RMSE of 0.09 m. due to static measurement, the ultrasonic sensor does not provide good results. It is better to use continuous measurement instead of static measurement for height estimations by ultrasonic. With the young wheat plant, the ultrasonic sensor measured plant height more accurately due to the natural curvature of the cluster leaves, which reflect sound waves effectively. Plants with high plant density in their bottoms reflect sound waves from the stem top, which is why mature plants show less height due to the loss of sound waves from their leaf tops.

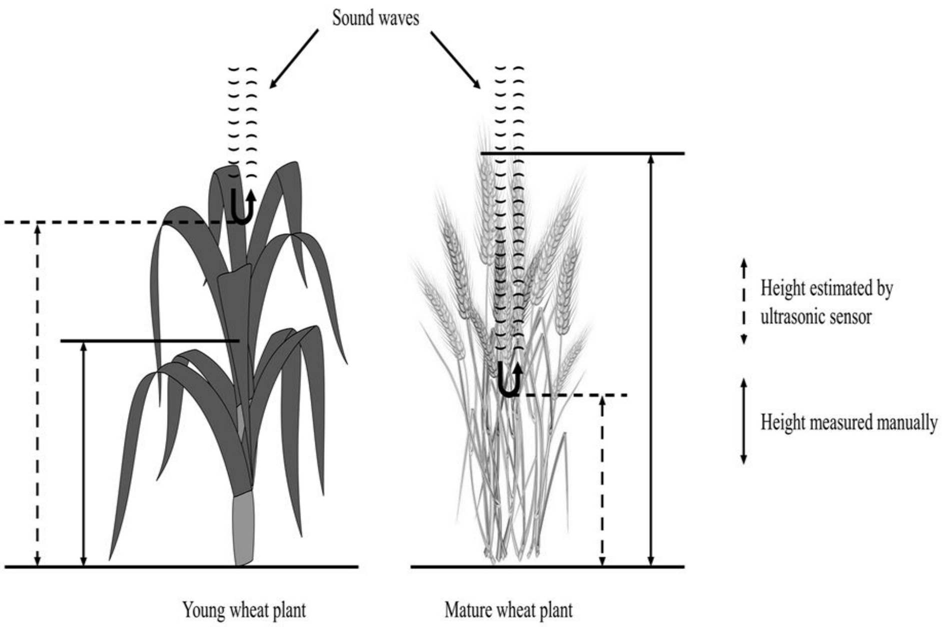

Figure 1: Two scenarios where ultrasonic sensor estimations disagree with manual measurements

Yuan *et al* (2019) developed a system by using a LiDAR sensor to scan rows of peanut plants in the field. In this research, the ground-based LiDAR used was a line-scan laser scanner with an angle resolution of 0.25˚, a scan angle of 100˚, and a scanning speed of 53ms. During field tests, a data acquisition platform for a ground-based LiDAR and an RGB camera was built and collected data were analyzed by an image processing algorithm. The image processing determined the height and width of the peanut canopy by comparing information about the Euler number, entropy, cluster count, and mean of several connected objects. The developed system and manual measurements had a good correlation R^2= 0.915. An average error of 9% was found between LiDAR and manual measurements, with an error range of 5 to 24 %. In the developed mobile data acquisition system, the LiDAR sensor shows errors caused by wind, meter stick position, human error, and vibrations. It was easier and more efficient to measure canopy height using the LiDAR sensor than manually measuring since it was not affected by sunlight

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Zhao *et al* (2010) developed a harvest area measurement system (HAMS) based on an ultrasonic sensor and differential global positioning system (DGPS) for yield map. To record data, ultrasonic sensors were mounted on both sides of each harvest header to detect crop presence and measure cutting width. The traveled distance of combine harvester was measured by a high-precision DGPS receiver. Results of field evaluation demonstrate that the developed HAMS is capable of reducing area errors and correcting yield errors. An area error of 6.89% was observed in a yield map calculated from DGPS tracks. An error of 1.08% was attributed to the traveled distance and a further 5.81% to the cutting width. The HAMS' error in measuring the area dropped to 0.95 percent. Between cutting and sensing, the HAMS estimated a time delay of 3 to 6s at the beginning and 1 to 7s at the end of the cutting. When measuring distances within 2.0 m, the ultrasonic sensor had a 0.09 m accuracy at a minimum measurement distance of 0.04 m. This made it suitable for measuring the cutting width.

However, ultrasonic sensors have better dynamic performance than SRF02 sensors, despite smaller maximum stable measurement distances.

A non-contact type grain flow sensor was designed and evaluated by Choi *et al* (2018) for a mid-sized full-feed type combine for rice, soybeans, and barley. The sensing process was performed just after the threshing, therefore there is no delay time effect, which is important in Asian countries, where typically small fields. The researcher tested commercially available non-contact type sensing modules, including microwave, optical, laser, and ultrasonic sensors, in a laboratory for crop yield measurement. Ultrasonic module performance was enhanced by increasing the module number and layout. Based on the results of a field test, the yield monitor sensor showed good potential for sensing grain flow for rice, soybeans, and barley, with R^2 values of 0.85, 0.78, and 0.83, and RMSE values of 126.14, 43.87, and 3739 g/s, respectively. RMSE and coefficients of determination for rice improved from 0.29 and 70.75 g/s to 0.86 and 34.13, from 0.32 and 70.23 g/s to 0.90 and 29.69, respectively, when the number of modules increased from 4 to 20, and for barley, from 0.22 and 72.86 g/s to 0.88 and 22.23, respectively. Researchers suggest that various signal processing and field tests under different field and crop conditions will need to be undertaken in order to improve and commercialize the technology.

4. Salient Points of Review of Literature

- A major limitation of the header control system was that it showed instability due to hydraulic actuator speed and crop conditions.
- The accuracy of ultrasonic sensors was dependent on target-to-sensor distance and terrain type and independent of the speed of the machine. (Leonard et al 1990).
- Optimum HHC system for combines minimizes harvest losses, chances of equipment damage and operator fatigue. (Lopes *et al 2002*).
- Significant time delays should be introduced to make reliable and accurate height adjustments (Singh 1983).
- Ultrasonic sensors can perform better than Infrared sensors for tile, plastic, wood, or sponge types of obstacles (Adarsh *et al* 2016).
- Due to the low position of soybean plants, improper control of the header height during harvesting is likely to cause poor harvesting and soil shoveling (Ni *et al* 2021).
- The ultrasonic sensor showed a maximum average error when the sensor's interference was analyzed at 30 cm apart (Escola *et al* 2011)

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