Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
**POLJOPRIVREDNA TEHNIKA**
Godina XLII
Broj 1, 2017.
Strane: 11 – 20

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
**AGRICULTURAL ENGINEERING**
Year XLII
No.1, 2017.
pp: 11 – 20

*UDK:* 613.6.027

*Originalni naučni rad*
*Original scientific paper*

# DESIGN AND DEVELOPMENT OF A YIELD MONITOR FOR GRAIN COMBINE HARVESTER

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***Abstract:*** Yield monitor is an important development in precision farming that allows the farmers to assess the yield variability within the field during crop harvesting. In advanced countries, developed yield monitors used for high hp combines cannot be applied on small indigenous combines due to design constraint and high cost. So, to spread the use of yield monitoring combines in India, it was necessary to develop an indigenous yield monitor for indigenous combines. For development of an indigenous yield monitor, components such as auxiliary tank, load cell, inductive sensor and display unit with micro-controller were identified. Indigenous yield monitor was developed by assembling designed/selected components on local manufactured combine. Yield monitor was also calibrated and evaluated in the field. The average value of measured yield was 3931.1 $kg \cdot ha^{-1}$ with a standard deviation of 2020.8 $kg \cdot ha^{-1}$ having coefficient of variation 51% which indicated that yield variability existed within the small and marginal field.

***Keywords:*** *precision agriculture, combine harvester, yield monitor, load cell calibration, yield variability*

## INTRODUCTION

Paddy-wheat is one of the most extensively adopted cropping patterns of Northern India. The total production of rice and wheat in India was 106.54 and 95.91 million tons in the year 2013-14. Similarly, in Punjab total production of rice and wheat was 11.27 and 10.17 million tons, respectively in the same year [1]. In Punjab, during last sixty

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years, agricultural production has increased manifold and this increase in production was because of advancement in technologies and innovations, use of fertilizers, pesticides, insecticides, high yielding, semi-dwarf and short duration varieties. Although, these technologies and innovations have improved the socio-economic conditions of the farmers but this has been done at a cost of environmental degradation [2]. The rice-wheat rotation in Punjab is very much resource demanding and has led to an agrarian crisis in Punjab in terms of depleting aquifers, reduced soil health, over exploitation of natural resources, unabated application of pesticides, loss of soil fertility and incorporation of non-biodegradable agricultural chemicals in soil and water. To increase the production and to protect the soil & environment from ill effects of chemicals, there is a need to adopt new farming techniques and technologies which help to protect our natural resources by using these resources optimally. Hence, precision farming is that technique which helps to achieve these goals. There are three basic steps i.e. assessing variability, managing variability and evaluation in precision farming. To assess the variability within a field or to get the first step of precision farming, yield monitoring devices are needed to develop.

A yield monitor is a recent development in precision farming and agricultural machinery that allows farmers to assess the yield variability in the field during harvesting of crop [3]. A yield monitor used in conjunction with a Global Positioning System (GPS) receiver records yield and location during harvest and give user an accurate assessment of how yields vary within a field. Although in advanced countries, high hp combines for large farms are available with yield monitors fitted as standard equipment or installed separately. An impact type flow meter was developed which measured grain forces on a curved circular tube using a load cell, near the top of a clean grain elevator [4]. An impact-type yield sensor with a curved plate was developed and tested in the lab; an error of 1 to 2% was noticed. However, the maximum error in the field was up to 3.5% [5].

An intelligent yield monitor for grain combine harvester was developed for harvesting the wheat crop. Field tests showed a linear relationship between actual yield and the output of the yield monitor. The error between measurement and prediction was less than 3%. It is concluded that the developed intelligent yield monitor is practical [6]. A modified version of optical sensor was designed to be specific to peanut mass-flow measurement. Test results showed that the output of the peanut mass-flow sensor was very strongly correlated with the harvested load weight, and the system’s performance was stable and reliable during the tests. [7]. A batch type yield monitor was developed which was having a load cell of capacity 700 kg with drum size 125x85x80 cm for grain combines, used to measure the spatial variation of grains for use as single unit or by putting directly in trailer. combine mounted batch type yield monitor was also developed by fitting an auxiliary tank of size 145×100×85 cm in the main tank and load cell at the bottom of the auxiliary tank. Yield variability of three different locations having C.V. of 5.46%, 27.56% and 35.34% were observed during the evaluation of batch type yield monitor [8].

These developed yield monitors are difficult to install on indigenous combines directly, because the sensors and systems usually design for those high hp combines and are very costly. Consequently, there was an essential need to develop an indigenous yield monitor by keeping various things in mind i.e. small combine, low cost and easy working & installation. Although, farmer could understand the reasons of yield variations through routine farm work, a combine harvester installed with indigenous yield monitor was expected to play an important role in establishing site specific crop management and spreading related technology to farmers. In this view, the present study was taken with the aim of design and development of an indigenous yield monitor for grain combine harvester.

## MATERIAL AND METHODS

This chapter deals with the methods and material applied for the design and development of an indigenous yield monitor for grain combine harvester.

*Design of Indigenous Yield Monitor.* Design of indigenous yield monitor includes (1) Conceptual design of yield monitor (2) Design of auxiliary tank (3) Selection of load cell, micro-controller 8051, inductive/speed sensor and display unit

*Conceptual Design of Indigenous Yield Monitor.* Conceptual design of indigenous yield monitor was about the theoretical planning of how this yield monitor could be developed physically. Yield monitor worked on the principle that the change in voltage of Wheatstone bridge circuit in load cell will be correlated with the geo-referencing points of the small fields and stored in the data logger to sense the yield of sites falling in the combine tank. Different types of components such as auxiliary tank, single point parallel type load cell, micro-controller with display unit and speed sensor were needed to design/select for the development of an indigenous yield monitor. These components were designed and selected due to their compatibility and operation in the yield monitor. Parallel beam type load cell was selected because of its easy installation at the bottom of the auxiliary tank. In this load cell design tension and/or compression loading is possible, provides easy installation and flexible application. For the data acquisition, a micro-controller 8051 with data presentation element was selected for the study, due to its accuracy, easy installation and wider applicability. Inductive sensor is also known as metal detective sensor as used to detect the metallic object without physical contact. A 3-wire inductive proximity sensor was selected for present study because of its accuracy, compatibility and easier installation. Fig. 1 shows the conceptual design diagram of combine harvester installed with different components of indigenous yield monitor.

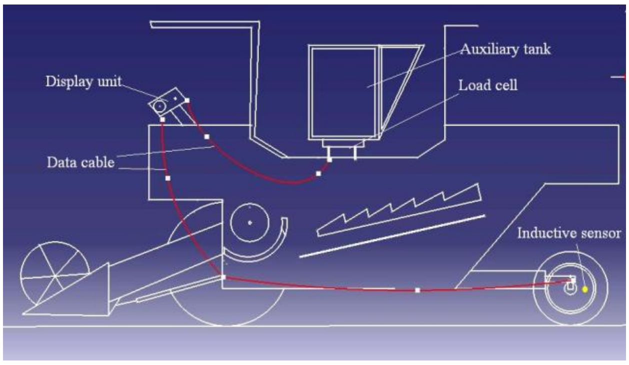


*Figure 1. Design diagram of combine harvester installed with different components of indigenous yield monitor*

*Design of Auxiliary Tank.* Auxiliary tank was an additional tank to collect the harvested grains and designed keeping in view that it should be fitted within the main tank of combine and there must have the provision and space to open auxiliary tank. It was made of steel sheet of 3 mm thickness and having a size of 1450 mm x 1000 mm x 850 mm. The angle iron of size 6 mm x 36 mm was used to make the frame of tank. The capacity of tank was about 200 kg for paddy grains.

*Selection of Load Cell, Inductive/Speed Sensor, Micro-controller and Display Unit.* Single point parallel load cell, having capacity of 700 kg, was selected due to its compatibility with the present monitoring system. In this load cell design, tension and/or compression loading were possible, provided easy installation and flexible application. A 3-wire inductive proximity sensor, a micro-controller 8051 for data acquisition and liquid cooled display unit for data presentation were selected for the indigenous yield monitor due to their accuracy, compatibility and easy installation.

*Development of Indigenous Yield Monitor.* Development of indigenous yield monitor includes mounting and assembling of yield monitor's components at combine harvester, working of yield monitor and software development.

*Mounting of Yield Monitor's Components at Combine Harvester.* Auxiliary tank was placed on the load cell bed within the main tank of combine harvester. Load cell was mounted under the auxiliary tank in between the designed load cell bed and platform. Micro-controller 8051 was used to store and process the data of load cell & inductive sensor and converted that data into readable form. Micro-controller was a small component and fitted inside the display unit which was placed at front of driver's cabin. The inductive/speed sensor was mounted on the rear axle to count the wheel revolution. It was mounted at rear wheels as these wheels have minimum slip in the field being the towed wheel.

*Assembling and Working of Indigenous Yield Monitor's Component.* After mounting the components of yield monitor on combine harvester, next step was to assemble these components with each others for accurate operation. Load cell, placed under the auxiliary tank was connected with Micro-controller's input pin 1. Inductive/speed sensor was fitted at the rear axle of combine and its signal wire was connected with Micro-controller's input pin 2. Micro-controller, installed inside of display unit was further connected with LCD of display unit, placed in front of operator's seat to present the output results. Fig. 2 shows the assembly of different components of indigenous yield monitor.

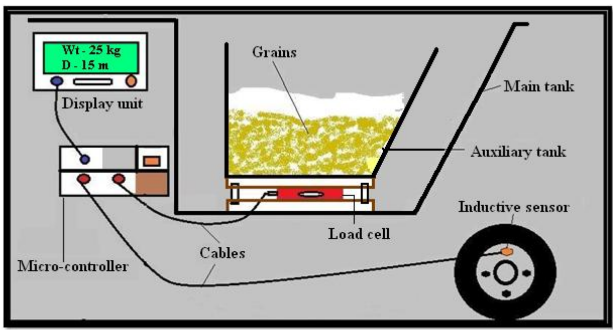


*Figure 2. Assembly of different components of indigenous yield monitor*

Harvested/processed grains coming through the elevator fall in the auxiliary tank and impact on load cell, fitted at the bottom of auxiliary tank. Load cell sent an analogue signal to signal condition element. Similarly speed/inductive sensor sent the signal to the conditioning element. In this element, analogue signal was converted into digital form and impurities of signal were removed. The digital data sent to the micro-controller for processing the data. Micro-controller stored and converted the data into understandable form. Display unit was the data presentation element which showed yield data in kilogram and distance in meter. Fig. 3 shows the block diagram of working operation of yield monitor.

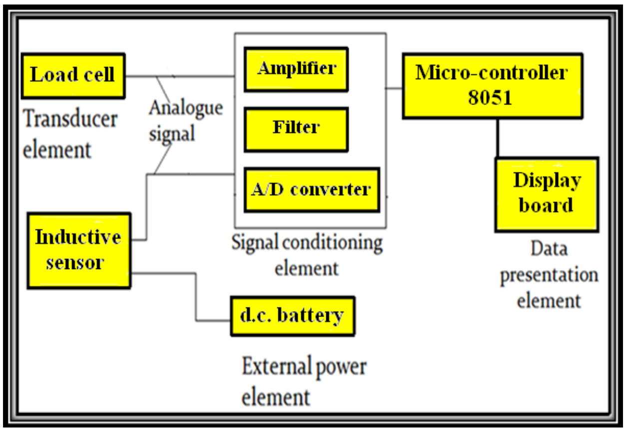


*Figure 3. Block diagram of working of indigenous yield monitor*

*Software Development.* Software in assembly language was developed to process the load cell and inductive sensor's data. The load cell calibrated data and inductive sensor pulse was fed to software for calculating the cumulative yield and travelled distance. The yield data in kilogram (kg) and traveled distance in meter (m) was displayed as output data by display unit/data presentation element.

*Calibration of Load Cell.* Load cell was calibrated by putting different loads in the auxiliary tank fitted with load cell placed under the auxiliary tank. Load cell connected with the micro-controller presented the 24 bits Hax value against the load (kg). The Hax value was converted into constant readable value with the help of available hexadecimal into decimal converter software. These constants values were converted into load (kg) with the help of calibration element. A straight line equation ($Y = 345.0x + 16146$) having $R^2 = 0.99$ was used to calculate the different values of load cell against different loads (kg). Tab. 1 show the calibration chart between load cell values and load/weight applied on load cell and R1, R2 and R3 represents the replications at different operating speed of combine harvester.

*Calibration and Accuracy of Inductive/Speed Sensor.* To test the sensing accuracy of speed sensor, a field was selected and a particular distance was measured with the help of measuring tape. Combine was run on field and sensor counted the wheel revolution. With the help of micro-controller, travelling distance of combine was calculated. After three replications, it was found that the measured distance and calculated distance was almost equal. Tab. 2 shows the accuracy of inductive sensor, where measured distance indicates the distance measured by measuring tape and calculated distance represents the distance calculated by micro-controller.

*Table 1. Calibration chart between load cell values and load/weight applied on load cell*

| *Sr. No* | *Load (kg)* | *Load cell value* | | | |
|---|---|---|---|---|---|
| | | *R1* | *R2* | *R3* | *Average* |
| *1* | *0* | *161319* | *161327* | *161329* | *161325* |
| *2* | *30* | *171510* | *171515* | *171475* | *171500* |
| *3* | *60* | *183009* | *183013* | *182978* | *183000* |
| *4* | *95* | *194107* | *194112* | *194081* | *194100* |
| *5* | *130* | *206129* | *206137* | *206139* | *206135* |

*Table 2. Accuracy of inductive sensor*

| *Sr. No* | *Measured distance (m)* | *Calculated distance (m)* | *Error (%)* |
|---|---|---|---|
| *1* | *50* | *48.75* | *2.5* |
| *2* | *50* | *50.75* | *-1.5* |
| *3* | *50* | *49.0* | *2.0* |

*Field Evaluation of Indigenous Yield Monitor*. Paddy crop was selected for field evaluation of indigenous yield monitor. Cumulative yield was measured and yield data was stored by the yield monitor after harvesting the crop at distance equal to circumference of rear wheel i.e. 2.5 meter of combine harvester. The variable yield data calculated from the measured cumulative yield data in each grid size of 10 $m^2$.

## RESULTS AND DISCUSSION

The yield monitor was evaluated for paddy crop of variety PR 118 to measure the yield variability with in the field.

*Yield Variability Measurement with Indigenous Yield Monitor.* Three strips of paddy crop were harvested at 3.0 km/h forward speed of combine harvester installed with indigenous yield monitor and yield variability data in each harvested grid of 10 $m^2$ area is shown in Fig. 4. In first strip the maximum and minimum yield was 9.09 kg and 1.21 kg in $15^{th}$ and $14^{th}$ grid of size 10 $m^2$ respectively. The moisture content of grains was varying from 15.6 to 15.9% on dry basis during the harvesting of selected crop area. In second strip the maximum and minimum yield was 7.09 and 1.7 kg in $13^{th}$ and $2^{nd}$ grid of size 10 $m^2$ respectively. Similarly, in third strip, the maximum and minimum yield was 7.46 and 0 .65 kg in $15^{th}$ and $4^{th}$ grid of size 10 $m^2$ respectively.

Yield variability maps of harvested strips at forward speed of 3.0 km/h are shown in Fig. 5. In first strip, the minimum yield i.e. below 2500 kg/ha was in the maximum area i.e. 37.5% followed by the yield having range 3750-5000 kg/ha in the area of 31.25%. The maximum yield i.e. more than 6250 kg/ha was in only 12.5% area. In second strip, the yield in the range 2500-3750 kg/ha was occupied the maximum area i.e. 37.5% followed by the yield range 5000-6250 kg/ha in the area of 18.75%. The maximum yield i.e. more than 6250 kg/ha was in only 12.5% area. In third strip, the minimum yield i.e. below 2500 kg/ha was in the maximum area i.e. 37.5% followed by the yield range 3750-5000 kg/ha in the area of 25%. The maximum yield i.e. more than 6250 kg/ha was in only 6.25% area.

The mean, standard deviation and coefficient of variation of yield data at forward speed of 3.0 km/h is given in Table 3. The average value of measured yield data in three harvested strips was 3931.1 kg/ha with a standard deviation of 2020.8 kg/ha having coefficient of variation 51%, which indicated that yield variability existed within the small and marginal field.

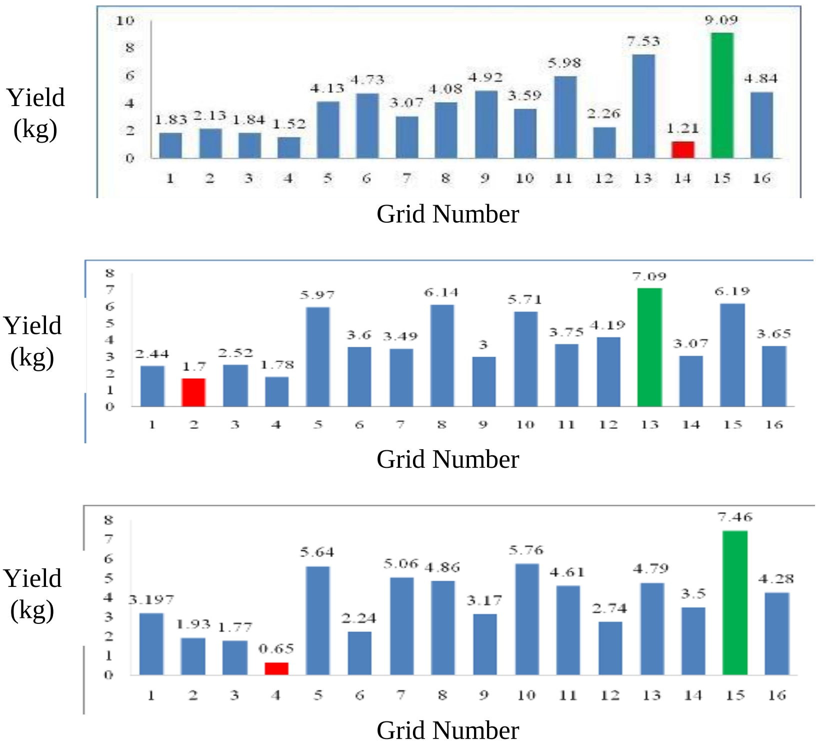


*Figure 4. Yield variability v/s Grid Numbers*

*Table 3. Mean, standard deviation (S.D.) and coefficient of variation (C.V.) at forward speed of 3.0 km/h*

| *Attributes* | *Forward speed (2 km/hr)* | | | |
|---|---|---|---|---|
| | *Strip 1 (R1)* | *Strip 2 (R2)* | *Strip 3 (R3)* | *Avg.* |
| *Mean (kg/ha)* | *3921.8* | *4018.1* | *3853.5* | *3931.1* |
| *Standard deviation (S.D)* | *2238.5* | *2051.9* | *1772.1* | *2020.8* |
| *Coefficient of variation (C.V) %* | *57* | *51* | *45* | *51* |

*Cost Analysis of Yield Monitor.* The major components of yield monitoring system were load cell, auxiliary tank and data acquisition system includes micro-controller, proximity sensor and display unit. The total cost of yield monitoring system comprising of load cell, auxiliary tank and data acquisition system was approximately Rs. 60000. Fixed cost of yield monitor includes depreciation, interest etc. and operating cost comprised of repair and maintenance of the system. Depreciation cost is calculated based upon the purchase price of the system. The interest rate for calculating the interest cost was assumed to be 10% and repair and maintenance cost was 5% of the purchase price. Total operational time for harvesting by combine harvester for rice, wheat and maize was assumed to be 150 days and field capacity of combine harvester was 0.75 hectare/hour. Hence, Total operational cost of yield monitor was calculated Rs. 12.5/hr or Rs, 16.50/ha.

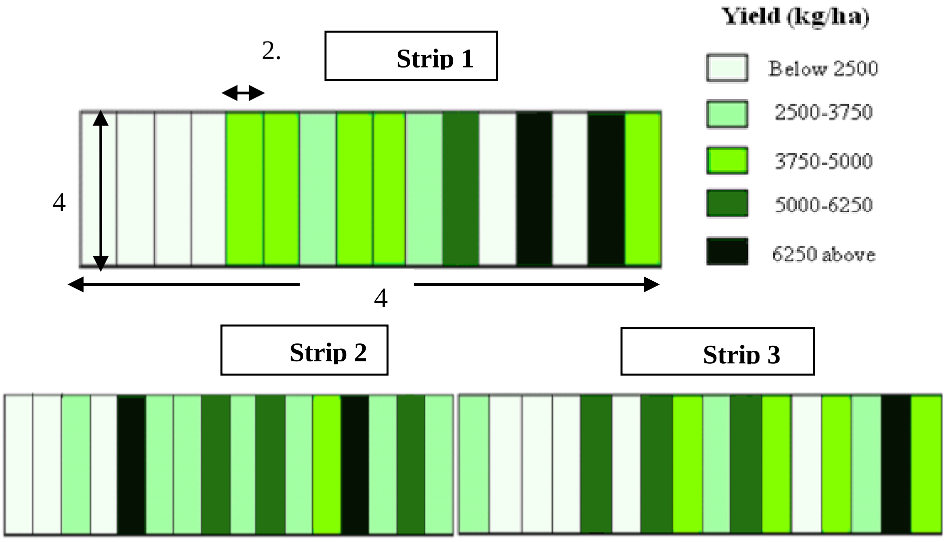


*Figure 5. Yield variability maps of harvested strips*

## CONCLUSIONS

The conceptual design of indigenous yield monitor was that when grains fell from combine elevator to auxiliary tank fitted in the main tank of combine, were measured by load cell fitted at the bottom of the tank. Single point parallel type load cell for yield measurement and inductive proximity sensor for distance measurement were selected for development of indigenous yield monitor due to their accuracy and compatibility. Micro-controller 8051 with display unit was selected to process the yield monitor's data. Indigenous yield monitor was developed by mounting and connecting these selected on locally manufactured combine harvester. Calibration of load cell indicated linearity between the loads (kg) and load cell values. The average value of measured yield was 3931.1 kg/ha with a standard deviation of 2020.8 kg/ha having coefficient of variation 51%, which indicated that yield variability existed within the paddy field.

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## KONSTRUKCIJA I RAZVOJ UREĐAJA ZA MERENJE PRINOSA NA ŽITNOM KOMBAJNU

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***Sažetak:*** Uređaj za merenje prinosa daje značajan doprinos razvoju precizne poljoprivrede tako što farmerima omogućuje merenje promenljivosti prinosa tokom žetve. U naprednim zemljama razvijeni uređaji ne mogu da se primene na malim kombajnima domaće proizvodnje zbog visoke cene i razlika u konstrukciji. Zato postoji potreba da se proširi upotreba monitora prinosa na domaćim kombajnima u Indiji, tako šro će se razviti domaći uređaj. Za razvoj ovog uređaja određene su domaće komponente: pomoćni rezervoar, ćelija tereta, indukcioni senszor i ekran sa mikro-kontrolerom. Uređaj od ovih komponenti je postavljen na domaći kombajn, kalibrisan i ocenjen u poljsim uslovima. Srednja vrednost izmerenog prinosa iznosila je 3931.1 $kg{\cdot}ha^{-1}$, sa standardnom devijacijom od 2020.8 $kg{\cdot}ha^{-1}$ i koeficijentom varijacije od

51%, što pokazuje da je promenljivost prinosa postojala u malom i zanemarljivom interval.

***Ključne reči:*** *precizna poljoprivreda, kombajn, merač prinosa, kalibracija ćelije tereta, promenljivost prinosa*

| | |
|---|---|
| Prijavljen:<br>*Submitted*: | 10.05.2016. |
| Ispravljen:<br>*Revised*: | |
| Prihvaćen:<br>*Accepted*: | 12.01.2017. |