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FULL-LENGTH RESEARCH ARTICLE

Design, Development and Performance Evaluation of a Portable Battery-Operated Litter Agitator Installed with AI-Controlled Obstacle-Avoidance Robot with Sensors

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Abstract

In commercial broiler poultry units, the farmers are required to stir the litter at least twice or thrice per week during the stay of birds until they are disposed.The manual method of stirring is laborious, time consuming and drudgery prone activity. So, a portable battery-operated poultry litter agitator has been developed and an artificial intelligence-controlled obstacle avoidance robot with sensors was also installed to get the ammonia and air quality data from the poultry farms. Performance evaluation of the agitator was done at 550–650 rpm and 800–900 rpm. A comparative study between manual and mechanical method of litter stirring was done by recording different parameters such as body weight of broiler birds, moisture content and bulk density at 2 cm and 4 cm litter depth. Apart from the reduction in drudgery, the time required for agitating poultry farm of area 220 m^2 with 2000 bird capacity was found to be 58 min, while manual method of agitation by using bamboo stick was found to be 2–2.5 h. At 2 cm litter depth, there was no considerable difference in litter bulk density and moisture content with mechanical agitation at 550–650 rpm and 800–900 rpm. At 4 cm litter depth, mechanical agitation with 800–900 rpm of element was found effective to reduce bulk density and moisture content which helps to maintain litter quality during grow out period. In mechanical agitation at 4 cm litter depth 59 g per day growth in body weight of broilers were observed at 550–650 rpm and 62 g per day growth in body weight was seen at 800–900 rpm. The cost of operation of litter agitation was reduced by 60% along with the drudgery compared to manual method by bamboo stick.

Keywords Battery-operated poultry litter agitator · DC motor · Bulk density · Raking · AI robot

Introduction

Poultry is one of the fastest growing segments of the agricultural sector in India currently. Deep litter system is commonly used all over the world for production of broilers. In this system, birds are kept inside the house all the time and feed and water are provided by feeders and drinkers. Poultry litter is generated as a mixture of poultry excreta (or manure), bedding materials (e.g., wood shavings, paddy husk, pine straw, sawdust, peanut hulls, and rice hulls), spilled feed, dead birds, bones, and feathers [12, 15]. The increasing demand for animal and protein products (e.g., egg, meat) has led to a high number of poultry feeding operations and massive quantities of poultry litter in confined areas [12]. This material acts as bedding to keep them warm and also to provide comfort.

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The floor space of 1.4 ft^2 per bird is provided in deep litter system. Initially before introducing chicks, 5 cm depth of litter is uniformly placed on concrete floor and then 2 cm per week litter is added on it to keep the litter dry and free. Litter is a waste by-product of poultry industry, which consists of faeces, bedding materials, wasted feed, and feathers. The grow out period of broilers from poultry house varies on an average about 47 days. Litter management is the most important operation in deep litter system (broiler production) to provide dry and friable litter throughout the grow out period [14]. Wet litter increases the risk of several health issues including footpad dermatitis, burnt hocks, podo-dermatitis, chronic respiratory disease (CRD) and breast blisters. It is also needed to avoid overly dry and dusty condition which can cause chick dehydration, inflammation, chicken respiratory diseases and reduction in body weight gain.

The problem of poor litter condition arises due to poor quality bedding material, inadequate litter depth, improper management of drinkers, not maintaining uniform bird density, cooling and ventilation system and improper litter stirring. Sources of moisture include drinker spillage and leaks, condensation and absorption from humid air, and frequent bird droppings. All these factors lead to increase in the moisture content, caking, ammonia formation, pungent offensive odours and various litter borne diseases in broilers. So, to overcome these problems, litter stirring is required at frequent intervals during grow out period of broilers to avoid poor litter condition.

When the moisture content of the litter increases, the cohesive forces between the litter particles also increase causing them to stick together tightly [2]. It prevents excreta being mixed in and forms caked litter on top layer of the litter. This caked litter condition requires large amounts of energy to break up and return to a friable state, which the poultry birds cannot do alone through their natural behaviours of working the litter. The process of litter agitation reduces the bulk density, particle size and increase friability of the litter. This litter racking breaks caked litter and mixes wet litter, poultry excreta, and dry litter and promotes aeration of litter. The ammonia which was trapped inside the litter cake is released to the atmosphere by breaking the litter material, due to which the aerobic microbial activity occur, which creates heat that promotes water evaporation from litter and accelerates decomposition of organic material. Aerobic decomposition produces less odour from poultry house than anaerobic decomposition. So, to overcome these problems, litter stirring practices is required at frequent interval during grow out period of broilers to avoid caking of litter [13, 17].

Conventional method of litter stirring using bamboo stick, rake or spade is a time consuming and drudgery prone activity. Improper litter stirring in the conventional method results in many diseases and other infections leading to bird mortality. During this process, the workers are exposed to ammonia gas and unpleasant odour inside poultry house for a long period of time in poultry units which may lead to severe health problems and sickness.

Electric operated poultry litter racking machines are available in the market but are not very much popular. It is operated by electric current which makes it difficult to use in between feeders and drinkers or another person is required to guide the cable. There are very high chances of electricity hazard inside the poultry house. Also, these machines are mounted with horizontal axis rotating steel blades on rotor shaft which may damage the concrete floor during working. Depth control unit is not provided is this machine.

Hence, a simple portable battery-operated poultry litter agitator is needed to be developed which does not damage the concrete floor and also reduces the cost of operation. With these views, the present study was conducted to design and develop a battery-operated poultry litter agitator.

Materials and Methods

A litter agitator was designed and developed for agitating poultry litter (Fig. 1). The machine consists of mainly two main units: (1) power transmission unit, and (2) agitating unit. The design also included appropriate factor of safety during the computation and determination of their dimensions. Following the theoretical design, the 2D and 3D model of the prototype was developed using Dassault Systems SolidWorks [4].

Design and Development of Poultry Litter Agitator

An effort was made for the development of a portable battery-operated machine capable for agitating litter without damaging the concrete floor beneath the litter since this raises the expense of floor repair when the litter is removed from the poultry house. The new equipment can make agitating process easier and more efficient. The machine is simple, has smaller number of components, simple in assembling, easy in manufacturing, handling and maintenance, easily mountable, susceptibility of vibration, low cost, easy to operate, low noise, durable, suitable depth control provision, safe and comfortable in operation and portable. The machine is light enough to be easily carried between compartments inside the poultry house. The noise level of the poultry litter agitator is low. The agitator is provided with appropriate dust control provision. The

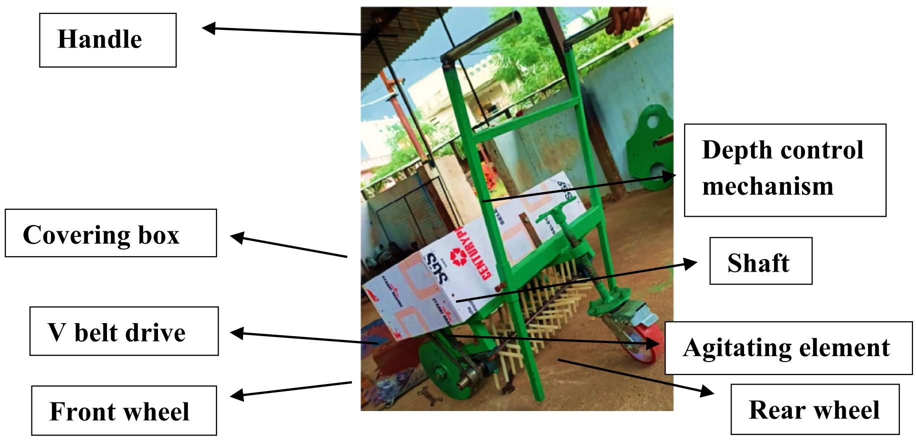


Fig. 1 Components of developed poultry litter agitator

machine pulverises the caked litter thoroughly and is simple to use.

Design Considerations

The following considerations were made in the design of poultry litter agitator. Working width of 54 cm is selected so that the agitator can complete agitation of litter between the feeders and drinkers in two passes. Agitator is walk behind push type and power is only supplied to agitating elements. DC motor is used to supply power to agitating elements which reduced the noise, while doing stirring operation. The capacity of battery is such that it is sufficient for 1 h of required operation.

Power Requirement of the Poultry Litter Agitator

For the operation of poultry litter agitator, the operator applies push force to the litter agitator to propel at a speed of about 0.45 kmh^{-1}. The developed machine is walk behind type. The power is only needed to agitate the litter material. The power requirement for the machine (P) was computed considering the power required for breaking the caked litter material.

Determination of Caked Litter Breaking Force and Power Requirement

It is the force required to break the caked litter material and it was measured by using universal testing machine (UTM). The undisturbed caked litter from poultry house was brought, which was used for analysis of rupture force of litter. The litter was placed on base platform of UTM and the probe was allowed to penetrate into the caked litter and the force required to break the litter was recorded in computer (Fig. 2).

It was found that to break 2 cm caked litter, 4.2 N force was required. On this basis, the power requirement was calculated as $P = \frac{2\pi NT}{60} = \frac{2\times3.14\times500\times4.2}{60} = 219.8$ W, where P = Power required to agitate the litter (W), N = RPM of agitating element, T = Torque (N-m) [T = F × r = 4.2 × 0.1 × 10 = 4.2 N-m].

The efficiency of DC motor = 85%, therefore, total power, $P = \frac{219}{0.85}$ = 257 W.

Thus, total power requirement for operating the poultry litter agitator, P = 257 watts and according to the market availability 250W DC motor was selected.

Power Transmission Unit

The 250 W DC motor was selected for poultry litter agitator. The speed available at motor pulley varies from 2400 to 2700 rpm. The suitable rotary speed of agitating element is 500 to 600 rpm. The higher the peripheral speed of agitating element, the better will be the pulverization of litter. Hence, the power transmission is designed to suit this range. The power transmission unit comprised of two subunits i.e. Belt and pulley drive and agitator shaft.

Design of Belt and Pulley Drive

Belt and Pulley drive was selected to transmit power from the motor shaft pulley to agitator shaft because of very high efficiency (95%), its durability against any joint failure, quiet in operation and it also works as a shock absorber. The following steps are involved in the design of V- belt drive and Pulley [16].

$$Velocity\ ratio(V_R) : \mathrm{V_R} = \frac{\mathrm{N_f}}{\mathrm{N_m}} = \frac{\mathrm{D_m}}{\mathrm{D_f}},$$

where N_f = speed of driver pulley in rpm, N_i = speed of driven pulley in rpm, D_f = diameter of driver pulley in metre, D_m = diameter of driven pulley in metre.

The preferred velocity ratio is 1.0, 1.2, 1.25, 1.4, 1.6, 1.8, 2.0, 2.25 3.15, etc. The transmission ratio, 1:2 was selected for design. To get the above velocity ratio, the

Fig. 2 Caked condition of poultry litter and analysis of rupture force of litter by universal testing machine

diameter of pulley attached with agitator shaft (driven shaft) was taken as 75 mm because the diameter motor shaft pulley (driving pulley) was 37.5 mm. for regulation of speed between input and output shaft suitable regulator will be provided.

Selection of Centre-to-Centre Distance of Belt

The maximum centre to centre distance between the two pulleys is never greater than 3 × ($D_f + D_i$) and less than diameter of larger pulley (D_i) [16]. Also, the minimum centre to centre distance is computed as $X = \frac{D_f + D_i}{2} + 3t = \frac{37.5+75}{2} + 3 \times 8 = 80.25\,\text{mm}$, where t = height of belt section.

Therefore, the considered centre to centre distance between motor shaft pulley to agitator shaft pulleys of poultry litter agitator (X_1) is 260 mm is well within above limit.

Length of Belt (L)

Selection of belt length of belt to transmit power from motor shaft pulley to agitator shaft pulley of poultry litter agitator. Pitch of belt length was computed by expression as shown elsewhere [9, 10, 16].

$$
\begin{aligned}
L &= \frac{\pi}{2}(\mathrm{D_f} + \mathrm{D_i}) + 2\mathrm{X} + \frac{1}{4\mathrm{X}}(\mathrm{D_f} - \mathrm{D_i})^2 \\
&= \frac{\pi}{2}(37.5 + 75) + 2 \times 260 + \frac{1}{4 \times 260}(37.5 - 75)^2 \\
&= 697.97\ \text{mm},
\end{aligned}
$$

where L = Pitch of belt length in mm, D_f = Diameter of drive (motor) pulley in mm (37.5 mm), D_i = Diameter of driven (agitator shaft) pulley (75 mm) and X = Distance between the centres of driving and the driven pulleys (260 mm).

For type A belt, 36 mm length was subtracted as factor for consideration [10]. Inside length of V belt was determined as Pitch length – F = 697.97 – 36 = 661.97 mm.

Therefore, a standard V-belt, type-A of size 36 having nominal inside length of 660 mm with top width 13 mm, bottom width 10 mm and 8 mm thick was selected.

Determination of Angle of Contact or Wrap (α)

The angle of contact or wrap or lap angle and cross belt drive on the small and big pulleys are expressed as shown elsewhere [3, 9, 10, 16].

$$
\text{Angle of contact or wrap } (\alpha) = \sin^{-1}\left(\frac{\mathrm{D_2} - \mathrm{D_1}}{2\mathrm{X}}\right) = 4.130
$$

The angle of contact (θ_{s1}) on pulley mounted on motor pulley was computed as

$$
\begin{aligned}
\theta_s &= 180 - 2\sin^{-1}\left(\frac{\mathrm{D_2} - \mathrm{D_1}}{2\mathrm{X}}\right) \\
&= 180 - 2\sin^{-1}\left(\frac{75 - 37.5}{260}\right) = 163.41^\circ
\end{aligned}
$$

For poultry litter agitator, the angle of wrap i.e. the bigger pulley (θ_b) mounted on agitator shaft was computed, as

$$
\begin{aligned}
\theta_b &= 180 + 2\sin^{-1}\left(\frac{\mathrm{D_2} - \mathrm{D_1}}{2\mathrm{X}}\right) \\
&= 180 + 2\sin^{-1}\left(\frac{75 - 35.5}{260}\right) = 161.41^\circ
\end{aligned}
$$

where, D_2 = Diameter of driven pulley (75 mm), D_1 = Diameter of driving pulley (37.5 mm), X = Distance between the centres of driving and the driven pulleys (260 mm).

Design of Agitator Shaft

A shaft is a rotating machine part which transmits power. The shaft design considers the computation of the correct shaft diameter to ensure satisfactory strength and rigidity, while transmitting power under different loading and operating situations. Design of shaft is based on the maximum shear stress theory. Shafts are usually subjected to torsion, bending, and axial loads. The solid shaft has little or no axial loading. According to the market availability, 30 mm diameter agitator shaft was selected. The power is supplied only to the agitator shaft, the movement of the system is entirely manual, with the operator guiding it as needed.

Design of Handle

As the equipment is to be operated by both male and female workers, 0.8 of the 5th percentiles of acromial height of female workers and 0.7 of the 95th percentile acromial height of female workers is to be considered [8]. Therefore, the handle height should be adjustable between 0.90 to 0.98 m. If fixed, then it should be 0.94 m.

Determination of Battery Capacity

Power requirement of DC motor, P_r = 250W.

Efficiency of battery, P_f = 0.80.

Therefore, total capacity/Total load of battery, $P_L = \frac{Pr}{Pf} = \frac{250}{0.80} = 312.5$W

Load current (Amps- Hour) = $\frac{Total\ Load(W)}{battery\ Voltage(volts)} = \frac{312.5}{24} = 13.02$ Ah

The battery life, Battery $_{(h)}$ = $\frac{Capacity(Ah)}{(P(W)/V(v))} = \frac{V(v)xCapacity(Ah)}{P(W)} = \frac{24\times13.02}{250} = 1.24$ hr

Where, capacity (Ah) = Load current, P (W) = Actual power required, V(v) = Voltage.

Hence, the battery of capacity 24 V, 12.5 Ah was selected to supply power to 500W DC motor.

Components of Poultry Litter Agitator

Agitator Frame

The frame was used to mount batteries, switch box and motor. The dimensions of frame were decided on the basis of gap between feeders and drinkers inside the poultry house. The frame of the litter agitator was made of MS angles and MS sheet. The length and width of frame were 600 mm and 540 mm respectively. The handle of the agitator was attached to frame. To protect the motor and other components from dust, while operating in the house, an appropriate cover with a box-like structure made of plastic was provided. The smaller two plastic wheels used to reduce the clearance at front of machine and to make machine light weight. The dimensions of two plastic wheels were 250 mm × 50 mm and connected by rigid shaft of diameter of 15 mm. The rear wheel supported by MS Square that provide direction to machine and it can be adjusted to control depth of operation of agitator. The machine is manually moved forward by exerting a push force through a handle linked to the main frame with a handle diameter of 30 mm. The handle's height from the ground was 900 mm.

Propelling Unit

The existing two rubber front wheels were replaced by smaller two plastic wheels to reduce the clearance at front of machine and to make machine light weight. The dimensions of two plastic wheels were 250 mm × 50 mm and connected by rigid shaft of diameter of 15 mm. The final prototype's rear wheel was the same as that of the previously constructed machine. The rear wheel supported by MS Square that provide direction to machine and it can be adjusted to control depth of operation of agitator. The machine is manually moved forward by exerting a push force through a handle linked to the main frame with a handle diameter of 30 mm. The handle's height from the ground was 900 mm.

DC Motor

The low torque DC motor were replaced by high torque capacity DC motor which used to supply the power to agitator shaft through belt pulley transmission system. The DC motor of capacity ratings 250W, 24 V were used to reduce noise of operation. It is operated by single 24 V battery. The rated speed and torque produced by motor was 3250 rpm and 1.10 N-m respectively.

Battery

The battery was used to supply current to DC motor to produce rotational power. Single lithium-ion battery was used to supply current to motor with nominal voltage of 24 V, rated capacity of 12.5Ah and 300 W/h.

Power Transmission System

The transmission system used to transmit rotation power from DC motor to agitator shaft through V belt drive system. The mechanism of power transmission was same as used in previously developed horizontal axis rotating element machine but the dimensions of pulley and thickness of belt were changed. The V belt drive system consists of a motor pulley and an agitator shaft pulley with diameters of 37 mm and 50 mm, respectively, as well as a belt with dimensions of 700 mm, 12 mm, and 3 mm. The motor and agitator shafts have diameters of 10 mm and 30 mm, respectively.

Agitator Shaft

The agitator shaft is the main component of machine to which litter pulverizing elements was attached. The agitator shaft gets the rotational power from V belt drive system and it is supported by bearings at the end on both sides to reduce the friction and noise, while working. The shaft's diameter was 25 mm.

Pulverizing Elements

The polyethylene wire was replaced by hard plastic spikes to pulverize the poultry litter. The elements were fitted to the agitator shaft in four rows which are parallel to each other. In each row 12 numbers of elements were present which strikes the litter at same time. The total number of elements was 48 provided on agitator shaft.

Litter Breaking Spikes

The litter breaking spikes was provided in front portion of machine to break, loose the compacted litter material and provide the favourable condition for agitator elements to do further pulverization. Three spikes held in vertical position and welded to frame of the agitator.

Development of AI-Controlled obstacle avoidance Robot with Sensors

The AI-controlled obstacle avoidance robot with sensors was developed to get the ammonia and air quality data from poultry house for performance evaluation of poultry litter agitator (Figs. 3 and 4). The main components of AI robot were divided into two parts i.e. operator guided propelling unit and Ammonia and air quality sensing unit.

Operator Guided Propelling Unit

The function of this unit is to propel the robot forward, backward and sideways according to obstacle sensed by ultrasonic sensor. It consists of the following components.

Ultrasonic Sensor An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. It consists of trigger pin (input pin) and eco pin (output pin). An ultrasonic sensor uses a transducer to send and receive ultrasonic pulses. The sensor head emits an ultrasonic wave and receives the wave reflected back from the target. The operating voltage of US sensor were 5 V with measuring distance of 2 to 80 cm.

Servo Motor SG90 The Servo Motor SG90 utilizes a regular motor and couples it with a sensor for positional feedback. The servo motor used to rotate approximately 180 degrees i.e. 90 degrees in each direction.

Arduino UNO with Micro Controller It is the main component used for decision making to decide the movement of robot. It receives the signals from US sensor, process the instruction and the provide output instructions to motor

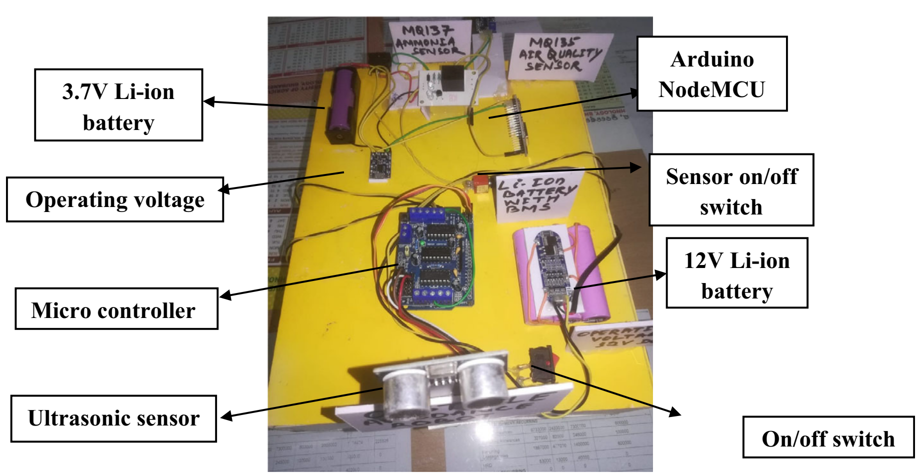
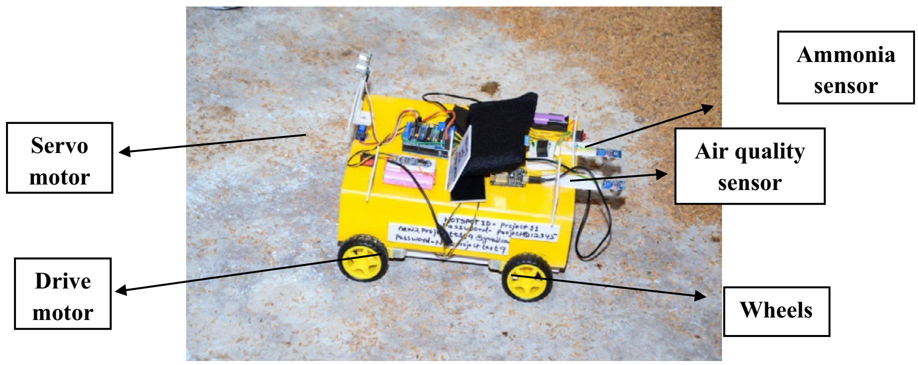


Fig. 3 Components of AI robot for sensing ammonia and air quality

Fig. 4 Obstacle avoidance AI robot



driver IC which in turns drive the motor to move the robot accordingly. The micro-controller consists of CPU, RAM and ROME.

Motor Driver IC A motor driver IC is an integrated circuit chip which is usually used to control motors in autonomous robots. Motor driver ICs act as an interface between microprocessors in robots and the motors in the robot.

Wheel Motor The wheel motor is a type of electric vehicle drive system connected to wheels of robot. The motors used are bidirectional. Each wheel of robot provided with motor to drive according to signals received from motor driver IC. The operating voltage of motor is 12 V. The battery used to supply power to motors of robot. The capacity of battery was 15 V provided.

Components of Ammonia and Air Quality Sensing Unit

The function of ammonia and air quality sensing unit is to detect the ammonia and air quality inside the poultry house and convert the input signals into analogue data and transfer the data to server to read in computer or mobiles through things peak website. The main components of sensing unit are as follows.

Li–ion Battery

The battery is used to supply the power to sensor. The operating voltage of sensor was 3.7 V. two batteries of capacity 3 V connected in parallel was used to supply the power.

Ammonia Sensor

Ammonia detector works on electrochemical principle. The MQ137 is an ammonia gas sensor which detects the presence of ammonia gas. As the concentration of N gas rises in the air, the conductivity of the sensor tends to become higher. Using a circuit, you can convert this change in conductivity to the output value which indicates the concentration of a gas. This sensor operates in an analogue voltage range of 2.5 V to 5 V. The ammonia concentration detection ranges from 10 to 300 ppm.

Air Quality Sensor

The MQ-135 sensor is used to detect composition gases such as NH_3, NOx, SO_2, CO, Benzene, smoke, CO_2. in poultry houses.

Arduino Node MCU

Node MCU is an open-source platform based on ESP8266 which can connect objects and let data transfer using the Wi-Fi protocol**.** It transfers the analogue data to server.

Selection Switch

The selection switch provided to select the sensor for reading the data. At single time only one sensor can work to give the data.

Results and Discussion

Performance Evaluation of Poultry Litter Agitator

The field performance evaluation of litter agitator was done by comparing it with manual method of litter raking. The performance evaluation of the agitator was done at 550 to 650 rpm and 800 to 900 rpm. A comparative study between manual and mechanical method of litter stirring was done by recording different parameters such as body weight of broiler birds, moisture content and bulk density at 2 cm and 4 cm litter depth. The experiment was carried out during grow out period of broilers. Four poultry farms of capacity 220 m^2 were selected. The poultry farms 1 and

Table 1 Effect of raking on body weight (g) of poultry birds

Age (day)	Litter Depth 2 cm			Litter Depth 4 cm		
	Farm 1 (manual raking)	Farm 2 (550–650 rpm)	Farm 2 (800–900 rpm)	Farm 3 (manual raking)	Farm 4 (550–650 rpm)	Farm 4 (800–900 rpm)
1st	55	55	55	55	55	55
10th	487	543	541	513	562	585
18th	876	986	994	972	1023	1120
22nd	1056	1153	1145	1175	1253	1334
25th	1239	1421	1425	1362	1441	1560
28th	1457	1605	1610	1526	1625	1743
31st	1691	1788	1796	1710	1810	1950
34th	1756	1980	1992	1882	1980	2145

2 were used for manual method of litter stirring and poultry farms 3 and 4 were used for mechanical method of stirring.

Effect of Raking on Body Weight (g)

It was observed that growth in body weight of broilers in mechanical method of agitation of litter was greater than manual method (Table 1). The growth of 52 g/day was observed in manual raking of litter, while 58 g/day was seen in mechanical agitation. Higher marketable weight of broilers was obtained in farm 2 and farm 4 which may be due to good maintenance of litter condition by lowering the bulk density and moisture content of litter which significantly reduces the effect of bacteria and other harmful diseases in broilers.

The effect of litter depth (A), RPM (B), and days (C) on the body weight of poultry birds was analysed using a randomized block design (RBD). The analysis shown significant effects of each independent factor as well as their interactions on the dependent variable (body weight). The key results are shown in the Table 2 below.

The study revealed that the independent factors such as litter depth, RPM, and days significantly influence the body weight of poultry birds. The ANOVA results demonstrated that each factor, as well as their interactions, had highly significant effects ($P < 0.01$) on body weight. These findings suggest that optimizing these parameters can enhance poultry management practices and improve growth outcomes.

Effect of Raking on Moisture Content (%) of Litter

Ammonia production by bacteria and its transportation to the litter surface depend on the moisture content [7, 11]. Francesch and Brufau [6] noted that high moisture content in litter can cause a rise in relative humidity, heavier and

Table 2 Effect of litter depth, RPM and days on body weight of poultry birds

Source	DF	SS	MS	*F*-value	SE	CD (5%)	CD (1%)
Replication	2	559.181	279.59	0.284			
Treatment	47	53,462,900	1,137,510	1153.417**			
Factor A (Litter Depth)	1	231,842	231,842	235.085**	3.701	10.392	13.764
Factor B (RPM)	2	615,387	307,694	311.997**	4.533	12.728	16.857
Factor C (Days)	7	52,319,500	7,474,220	7578.747**	7.402	20.785	27.528
Interaction AxB	2	27,772	13,886	14.080**	6.410	18.000	23.840
Interaction AxC	7	56,833	8,119.01	8.233**	10.468	29.394	38.930
Interaction BxC	14	154,565	11,040.4	11.195**	12.821	36.000	47.679
Interaction AxBxC	14	56,968.3	4,069.16	4.126**	18.131	50.911	67.428
Error	94	92,703.5	986.207				
Mean	1194.222 g						
CV	2.630%						

**Indicates significance at $P < 0.01$

Table 3 Effect of raking on moisture content (%) of poultry litter

Age (day)	Litter Depth 2 cm			Litter Depth 4 cm		
	Farm 1 (manual raking)	Farm 2 (550–650 rpm)	Farm 2 (800–900 rpm)	Farm 3 (manual raking)	Farm 4 (550–650 rpm)	Farm 4 (800–900 rpm)
1st	11.20%	11.20%	11.20%	11.20%	11.20%	11.20%
10th	14.43%	13.42%	13.55%	17.11%	15.44%	13.34%
18th	18.31%	15.23%	14.46%	21.32%	18.77%	16.35%
22nd	23.51%	17.01%	14.77%	24.26%	20.02%	17.76%
25th	24.26%	17.34%	16.68%	26.44%	22.45%	19.53%
28th	26.04%	19.56%	17.02%	29.66%	25.32%	22.43%
31st	27.02%	19.62%	19.33%	30.42%	26.24%	23.53%
34th	28.30%	20.45%	19.87%	32.56%	28.24%	23.77%

larger manure loads that make handling them more difficult and a quicker release of ammonia into the environment.

The litter moisture content at 2 cm depth increased from 11.20 to 28.30% with manual raking in farm 1, from 11.20 to 20.45% with mechanical agitation at 550 to 650 rpm, and from 11.20 to 19.87% at 800 to 900 rpm in farm 2 during rearing period of broilers (Table 3). The moisture content of farm 2 was found to be lower than that of farm 1. This was due to fine pulverization of litter, which facilitates in moisture evaporation from litter and aeration, keeping litter dry during the rearing period. The mechanical agitation of poultry litter maintains the litter moisture within the acceptable limit.

The litter moisture content at 4 cm depth increased from 11.20 to 30.56% with manual raking in farm 3, from 11.20 to 28.24% with mechanical agitation at 550 to 650 rpm, and from 11.20 to 23.77% at 800 to 900 rpm in farm 4 during rearing period of broilers. The moisture content in farm 4 was less than the farm 3 which may be due to fine pulverization of litter which helps in moisture evaporation from litter that keep litter dry during rearing period. The litter moisture content was less at 800 to 900 rpm when compared to 550 to 650 rpm in farm 4 which may due to lower bulk density at 800 to 900 rpm of agitating element.

The effect of litter depth (A), RPM (B), and days (C) on the moisture content of poultry litter was analysed using a randomized block design (RBD). The analysis demonstrated significant effects of each independent factor as well as their interactions on the dependent variable (body weight). The key results are shown in the Table 4 below:

The study shows that the independent factors such as litter depth (A), RPM (B), and days (C) have a significant impact on the moisture content of poultry litter. The ANOVA results indicate that all factors, along with their interactions, have highly significant effects ($P < 0.01$) on moisture content. The extremely high F-values for factors A, B, and C highlight their critical role in determining moisture levels. Additionally, significant interactions

Table 4 Effect of litter depth, RPM and days on moisture content (%) of poultry litter

Source	DF	SS	MS	F-value	SE	CD (5%)	CD (1%)
Replication	2	4.22832	2.11416	10.498**			
Treatment	47	4746.79	100.995	501.500**			
Factor A (Litter Depth)	1	375.972	375.972	1866.916**	0.053	0.149	0.197
Factor B (RPM)	2	839.822	419.911	2085.098**	0.065	0.182	0.241
Factor C (Days)	7	3139.17	448.453	2226.826**	0.106	0.297	0.393
Interaction AxB	2	20.9698	10.4849	52.063**	0.092	0.257	0.341
Interaction AxC	7	93.6853	13.3836	66.457**	0.150	0.420	0.556
Interaction BxC	14	243.746	17.4104	86.453**	0.183	0.514	0.681
Interaction AxBxC	14	33.4212	2.38723	11.854**	0.259	0.728	0.964
Error	94	18.9304	0.201387				
Mean	19.873 g						
CV	2.258%						

** indicates significance at $P < 0.01$

between these factors suggest that their combined influence should be carefully managed to optimize litter moisture conditions. The low coefficient of variation (CV = 2.258%) further emphasizes the consistency of the results, indicating a reliable experimental design.

Effect of Raking on Bulk Density (g/cm^3) of Litter

The bulk density of litter at 2 cm depth increased from 0.25 g/cm^3 to 0.49 g/cm^3 with manual raking in farm 1 and from 0.26 g/cm^3 to 0.34 g/cm^3 with mechanical agitation at 550 to 650 rpm and from 0.25 g/cm^3 to 0.32 g/cm^3 at 800 to 900 rpm in farm 2 during rearing period of broilers (Table 5). The bulk density of litter with mechanical agitation was lower than manual raking because of fine pulverization of caked poultry litter.

The bulk density of litter at 4 cm depth increased from 0.25 g/cm^3 to 0.59 g/cm^3 with manual raking in farm 3 and from 0.25 g/cm^3 to 0.48 g/cm^3 with mechanical agitation at 550 to 650 rpm and from 0.25 g/cm^3 to 0.37 g/cm^3 at 800 to 900 rpm in farm 4 during rearing period of broilers. The bulk density of litter with mechanical agitation was lower than manual raking, because of fine pulverization of caked poultry litter and there was considerable difference was observed in bulk density of litter at 4 cm depth in farm 4. The bulk density at 800 to 900 rpm was lower than 550 to 650 rpm. This variation was due to more caking of litter material which requires more force, repetitive action to break and pulverize the litter. According to Bernhart et al. [2], the energy needed to efficiently break down the tightly cohesive particles is provided by the machinery used during litter turning. Litter turning and drying increase the litter's flowability and friability, while decreasing its bulk density and particle size. El-Shabrawy [5] found that the bulk density was reduced to 0.3 g/cm^3 at a blade revolution of 960 rpm, with a working depth of 5 cm on litter.

The effect of litter depth (A), RPM (B), and days (C) on the bulk density of poultry litter was analysed using a randomized block design (RBD). The analysis demonstrated significant effects of each independent factor as well as their interactions on the dependent variable (body weight). The key results are shown in the Table 6 below.

Litter depth (A), RPM (B), and days (C) significantly affect the bulk density of poultry litter, with all factors and most interactions showing highly significant effects ($P < 0.01$). The high F-values for A, B, and C highlight their importance. The AxB and BxC interactions are also significant, while AxBxC is not. The consistency of results is reflected in a CV of 6.987%, confirming the reliability of the experiment.

Effect of Raking on *Ammonia* and Air Quality in Poultry Farms

An artificial intelligence control obstacle avoidance robot with sensors was installed in the poultry litter agitator to get the ammonia and air quality data from the poultry farms. The ammonia and air quality inside the poultry house was detected by using sensor mounted on AI robot. These sensors give real time data of change in ammonia and air quality concentration in poultry house before agitation of litter and after agitation of poultry litter (Table 7).

The concentration of ammonia and air quality index in poultry house before agitation of litter was in the range of 19 to 28 ppm and 113 to 186 ppm. The concentration of ammonia and air quality index just after agitation was observed in the range of 20 to 32 ppm and 127 to 198 ppm. This increased concentration was reduced in the range of 14 to 23 ppm of ammonia and 96 to 148 ppm of air quality index when concentration was measured after 6 h of agitation.

Table 5 Effect of raking on bulk density (g/cm^3) of poultry litter

Age (day)	Litter depth 2 cm			Litter depth 4 cm		
	Farm 1 (manual raking)	Farm 2 (550–650 rpm)	Farm 2 (800–900 rpm)	Farm 3 (manual raking)	Farm 4 (550–650 rpm)	Farm 4 (800–900 rpm)
1st	0.25	0.25	0.25	0.25	0.26	0.26
10th	0.32	0.27	0.27	0.35	0.32	0.3
18th	0.39	0.30	0.27	0.44	0.36	0.32
22nd	0.43	0.30	0.28	0.47	0.39	0.33
25th	0.45	0.32	0.29	0.55	0.42	0.35
28th	0.47	0.33	0.30	0.56	0.44	0.35
31st	0.49	0.33	0.31	0.58	0.47	0.36
34th	0.49	0.34	0.32	0.59	0.48	0.37

Table 6 Effect of litter depth, RPM and days on bulk density (g/cm^3) of poultry litter

Source	DF	SS	MS	F-value	SE	CD (5%)	CD (1%)
Replication	2	0.0058875	0.00294375	4.312*			
Treatment	47	1.29598	0.027574	40.386**			
Factor A (Litter Depth)	1	0.154056	0.154056	225.638**	0.003	0.009	0.011
Factor B (RPM)	2	0.407262	0.203631	298.248**	0.004	0.011	0.014
Factor C (Days)	7	0.539705	0.0771007	112.926**	0.006	0.017	0.023
Interaction AxB	2	0.0238292	0.0119146	17.451**	0.005	0.015	0.020
Interaction AxC	7	0.0364604	0.00520863	7.629**	0.009	0.024	0.032
Interaction BxC	14	0.121826	0.00870188	12.745**	0.011	0.030	0.040
Interaction AxBxC	14	0.0128375	0.000916964	1.343	0.015	0.042	0.056
Error	94	0.0641792	0.000682757				
Mean	0.374 g						
CV	6.987%						

** indicates significance at $P < 0.01$

Table 7 Ammonia and air quality in poultry house before and after litter agitation

Readings	Before agitation		After agitation		After 6 h	
	Ammonia (ppm)	Air quality (ppm)	Ammonia (ppm)	Air quality (ppm)	Ammonia (ppm)	Air quality (ppm)
1.	23	146	24	127	19	123
2.	26	174	27	164	16	104
3.	21	155	22	185	20	117
4.	27	162	24	171	15	127
5.	28	139	26	151	17	94
6.	21	186	25	144	21	122
7.	19	156	23	167	19	141
8.	23	142	25	192	15	109
9.	18	182	27	145	18	131
10.	24	153	23	162	14	108
11.	28	154	25	188	20	125
12.	27	167	30	175	22	145
13.	20	171	23	177	19	134
14.	23	145	21	153	16	148
15.	25	149	26	186	21	128
16.	27	168	31	149	23	138
17.	21	149	28	157	15	116
18.	23	139	21	145	19	112
19.	19	153	28	169	14	124
20.	24	113	26	150	20	131
21.	27	136	29	173	23	127
22.	25	146	26	198	18	96
23.	23	177	22	152	20	108
24.	26	159	29	187	16	127
25.	23	139	20	181	18	119
Mean	24	154	26	166	18	133

Beker et al. [1] described how different ammonia concentrations of 0, 30 and 60 ppm affected the productivity of commercial broilers. As the ammonia concentration rose from 0 to 60 ppm, there were no discernible changes ($P \geq 0.05$) in the final body weight, feed consumption, or body weight gain. At the 60 ppm ammonia level, however, the gain-to-feed ratio was discovered to be significantly lower ($P = 0.05$). According to Wang et al. [18], body weight and feed-to-gain ratio were found to be significantly ($P \leq 0.05$) reduced by exposure to 52 ppm ammonia, by 5.0% and 3.0%, respectively. The research findings indicate that broiler chick growth performance was adversely affected by elevated levels of ammonia concentration.

Conclusions

The study developed a portable, battery-operated poultry litter agitator with an AI-controlled, obstacle avoidance robot to gather ammonia and air quality data from poultry farms. It evaluated the agitator's performance at 550–650 rpm and 800–900 rpm, comparing it with manual litter stirring methods. Key parameters measured included the body weight of broiler birds, moisture content, and bulk density at different litter depths. The mechanical method was found to be less labour-intensive and quicker than manual raking. The performance of the developed litter agitator was found to be satisfactory. The bulk density of litter with mechanical agitation was lower than manual raking. At 2 cm litter depth, there was no considerable difference in litter bulk density and moisture content with mechanical agitation at 550 to 650 rpm and 800 to 900 rpm. At 4 cm litter depth, mechanical agitation with 800 to 900 rpm significantly reduced bulk density and moisture content. Further, long-term studies should be carried out to assess the impact of mechanical agitation on poultry health and farm productivity over time.

Author Contributions Conceptualization was done by S.K. Swain; methodology was done by R.B. Gaddamwar, A.K. Dash, S.K. Swain; validation was done by A.K. Dash, D. Behera, S.K. Swain, S.K. Dash, L. Samal; formal analysis was done by S.K. Swain; investigation was done by R.B. Gaddamwar; resources was done by S.K. Swain, S.K. Dash, L. Samal; data curation was done by S.K. Swain; writing – original draft preparation were done by L. Samal; writing – review and editing were done by S.K. Swain, S.K. Dash, L. Samal; supervision was done by S.K. Swain. All authors have read and agreed to the published version of the manuscript.

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Declarations

Conflict of interest The authors declare no conflict of interest related to this article.

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