Design and Development of Multipurpose Agricultural Robot

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October 4, 2023

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***Abstract*-This research paper introduces an autonomous agricultural robot powered by batteries, capable of performing a range of tasks, including ploughing, leveling, seed sowing, and seedling. The robot's frame is constructed from mild steel, and it uses DC motors for power transmission. A 3-DOF mechanism has been developed, with power and torque calculated at 0.01789 KW and 1.139 Nm, respectively. For sowing wheat, a rotating drum with a hopper mechanism is employed, while a four-bar mechanism is used for seedling purposes. These components are then integrated into a remotely controlled robotic vehicle. The successful implementation of this robot demonstrates its potential to transform agricultural practices by offering efficient and precise automation for a variety of farming tasks. The objective of this project is to improve the quantity of crops while working in small spaces and gaining a better understanding of operational principles of agricultural robots.**

Keywords: ***Seed sowing, Seedlings, Autonomously, Rotating Drum, Precise, automation***

I. Introduction

Agricultural robotics is an emerging field that is changing the way we farm[1]. The use of robots in agriculture can help to increase efficiency, reduce labor costs, and improve crop yields. In recent years, there has been a significant amount of research into the design and development of agricultural robots that can perform various tasks such as plowing, leveling, seed sowing, and seedling. In this literature review, we will discuss some of the recent developments in the design and development of multipurpose agricultural robots. The sustainable growth of Pakistan's agriculture sector is vital for the country's rural development and food production. This sector has a significant impact on employment and foreign exchange revenues, as well as serving as a source of industrial raw materials, making it closely linked to the overall economy. Agriculture accounts for 22.7% of the GDP and employs about 37.4% of the labor force in Pakistan[2]. Wheat, cotton, and rice are the most important crops in Pakistan and serve as staple foods in the country. Agricultural robots are becoming increasingly important in modern agriculture. The design and development of multipurpose agricultural robots that can perform various tasks such as plowing, leveling, seed sowing, and seedling is a rapidly growing field. These robots have the potential to revolutionize the way we farm, increasing efficiency and reducing labor costs. Seed sowing robots and seedling robots are two types of robots that are specifically designed to perform these tasks. As technology continues to advance, we can expect to see more innovative designs in the field of agricultural robotics.

Agriculture involves the cultivation of crops and livestock. Efficient and precise plowing, seed sowing, and leveling can save time and labor while increasing the GDP[3],[4]. In Pakistan, the development of an autonomous plowing, seed sowing, and leveling robot can improve crop growth and boost the economy.

It is common knowledge that plowing, seed sowing, and leveling are crucial for crop cultivation[5]. However, in Pakistan, these processes are not carried out with precision. For instance, seeds may not be placed at the correct spacing, resulting in inadequate sunlight and overlapping rows, which reduces crop yields. These issues have motivated us to develop a model that can perform these tasks accurately to enhance crop growth.

A. What is seed sowing

Seed sowing refers to the act of planting seeds in the ground for the purpose of growing crops or plants[6]. This process involves placing the seeds in the soil at the right depth and distance, as well as ensuring that they receive sufficient water and nutrients to sprout and thrive. The success of the crop and the expected yield are dependent on the quality of seed sowing[7], which makes it a critical aspect of agriculture.

B. Soil Analysis

Soil analysis in agriculture involves evaluating soil properties such as pH, nutrient levels, and organic matter content to determine its suitability for plant growth[8]. It helps farmers make informed decisions regarding fertilization and management practices[9] to optimize crop yield.

C. Approach

Recently, there has been a significant acceleration in the development of autonomous vehicles like robots in the agricultural industry[10],[11]. These robots are being designed to serve various purposes. Virtual prototyping is an essential aspect of this process, involving the creation of new structures. Using a computer-aided design technique called virtual prototyping (VP), accurate simulations are employed to address significant challenges, including physical layout, operational concepts, specifications, and dynamic analysis.

What world has done so far

The use of automation is becoming increasingly popular across various industries, including agriculture. Historically, farming activities such as planting, irrigation, fertilization, monitoring, and harvesting have required a significant amount of repetitive and labor-intensive work, resulting in low speed and productivity over a large area of crops. However, with the advent of modern technologies, robots are capable of performing these tasks with minimal human intervention[12]. There is a growing demand for agricultural technologies that are more accessible, user-friendly, and easily implemented by farmers.

There are many researches that intends to develop an agricultural robot which performs multiple tasks which include plowing, seed sowing seedling leveling and water spraying[13],[14],[15].

During the previous year, senior students from our university while working on Agriculture made a seedling and seed sowing robot and also in the same year, another group of senior students made plowing and leveling robot.

The project aims to develop an autonomous working prototype capable of performing various tasks such as ploughing and levelling. Research will be conducted on agricultural robots and their operations in a small area. Simulation of the prototype's chassis, plough, and leveler will be carried out using ANSYS Workbench and ADAMS, utilizing analysis of the mechanical structure[16].

Figure I.1 Fabricated Model of Plowing and Leveling Robot

The second project involves designing and creating a smart robot that can carry out various agricultural tasks while being controlled by an Android cell phone. Distributing seeds and seedlings are examples of agricultural tasks that were performed by this robot[17].

Figure I.2 Fabricated Model of Seedling and Seed Sowing Robot

There were many sensors and vision based multitasking robots that are made in previous years and are capable to perform precision agriculture[18],[19],[20].

The primary purpose of agricultural robots is to automate a range of farming tasks, such as planting, irrigation, fertilization, monitoring, and harvesting. These robots are created to increase efficiency, lower labor costs, and optimize crop yield while minimizing the environmental impact of farming activities[21-23]. In addition, they can provide real-time data to farmers on soil conditions, crop health, and weather patterns, allowing for informed decision-making and precise management practices[24].

II. Design and Modeling

The necessary components that a design must possess to make it an effective story are called design requirements[25]. The robot has to move within a controlled environment, such as a road or an agricultural field, in accordance with the original specifications proposed for its design and function. It is imperative for the robot to operate its mechanism accurately and modify its direction based on commands[26]. The subsequent phase in our project after analyzing the soil and studying seedlings, seed sowing, ploughing, and leveling is to create the robot design through Solid Works. The design will comprise the following components: chassis, seed sowing mechanism, seedling mechanism, plough, and levelers.

A. Chassis

In the design of a robot, the chassis serves as the basis that holds all other components together. In our project, the chassis is required to withstand the strains and tremors generated by the motors of the two modules. Mild Steel was selected as the material for the robot's chassis because of its toughness and malleability.

B. Plough

To facilitate ploughing, we created three ploughs spaced 170mm apart, with a 20-degree rake angle. To regulate its motion, we employed a rack and pinion mechanism. Plough is made of mild steel because it has greater strength then Aluminium.

C. Seedling Mechanism

In order to design the seedling mechanism, we utilized a cross four-bar mechanism concept. To pick up the plant from the tray above and place it into the soil, a connector link was employed in this mechanism. Our CAD model incorporated two seedling mechanisms spaced 250mm apart.

D. Full Assembly of Mechanism

This mechanism consists of plough and a roller at the front then comes the seedling mechanism which is controlled by four bar mechanism then comes the seedling mechanism and at the end is roller which is controlled by link mechanism and this whole mechanism is four wheel driven.

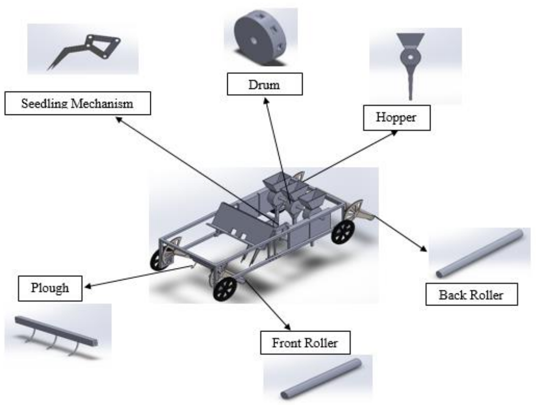

Figure II.1 Demonstration of Model

III. Mathematical Modeling

This section involved the completion of analytical and mathematical tasks, which included determining the weight of components, calculating the soil pressure on the plough, analyzing the four-bar mechanism used in the seed sowing and seedling process, and determining the power and torque needed for the motors to meet the requirements of the prototype and its mechanisms.

D. Kinematics of Cross Four Bar Mechanism for Seedlings

For the purpose of the seedling mechanism, kinematic analysis is used to determine the displacement, velocity, and acceleration of four bars.

a) Displacement Analysis

Using Cosine rule

$$BD = \sqrt{L_1^2 + L_2^2 - 2L_1L_2\cos\theta_2}$$

$$BD = 161.55\ mm$$

$$\gamma = \cos^{-1}\left[\frac{L_3^2 + L_4^2 - BD^2}{2L_3L_4}\right] \qquad 4.1$$

$$\gamma = 80.40\ mm$$

$$\theta_3 = 2\tan^{-1}\left[\frac{-L_2\sin\theta_2 + L_4\sin\gamma}{L_1 + L_3 - L_2\cos\theta_2 - L_4\cos\gamma}\right] \qquad 4.2$$

$$\theta_3 = 30.7^\circ$$

$$\theta_4 = 2\tan^{-1}\left[\frac{L_2\sin\theta_2 - L_3\sin\gamma}{L_4 + L_2\cos\theta_2 - L_1 - L_3\cos\gamma}\right] \qquad 4.3$$

$$\theta_4 = 111^\circ$$

By these formulas and calculations, we get the graphs of angular displacement for seedling mechanism.

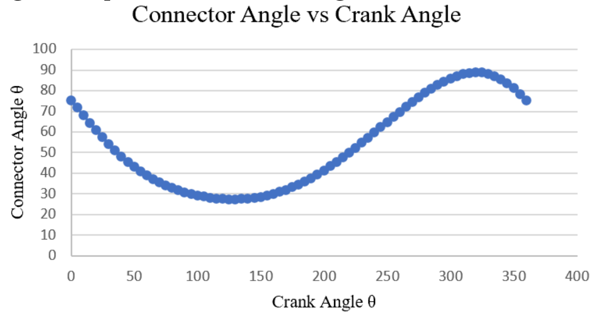

Figure III.1 Connector vs Crank Angle graph

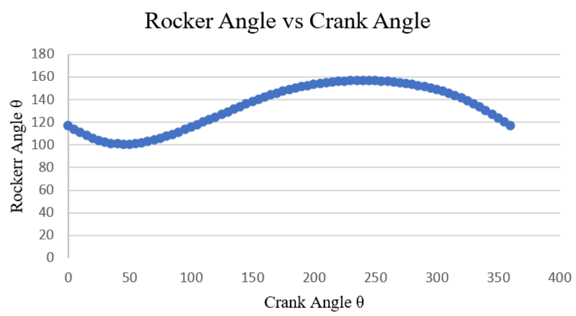

Figure III.2 Rocker arm vs Crank Angle Graph

The figure 4.1 and figure 4.2 above depict how the angular displacement of the rocker and connector changes as the crank completes a full rotation of 360 degrees. According to the first figure, the connector exhibits a maximum angular displacement of 88.7 degrees at approximately 320 degrees of crank rotation, and a minimum angular displacement of 27.27 degrees at around 130 degrees of crank rotation. In the second figure, the rocker shows a maximum angular displacement of 156.6 degrees at approximately 240 degrees of crank rotation, and a minimum angular displacement of approximately 100.34 degrees at around 45 degrees of crank rotation.

b) Velocity Analysis

$$\omega_3 = -\omega_2\left[\frac{L_2\sin(\theta_4 - \theta_2)}{L_3\sin\gamma}\right] \qquad 4.4$$

$$\omega_3 = -0.1908\,\frac{rad}{s}$$

Similarly

$$\omega_4 = -\omega_2\left[\frac{L_2 sin(\theta_3 - \theta_2)}{L_4 sin\gamma}\right] \qquad 4.5$$

$$\omega_4 = 0.422\,\frac{rad}{s}$$

By these formulas and calculations, we get the graphs of angular velocity for seedling mechanism

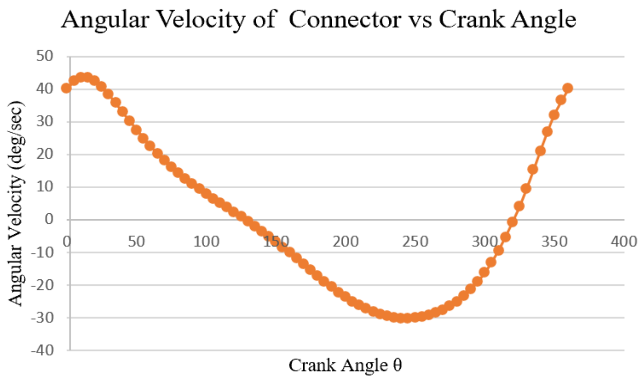

Figure III.3 Angular Velocity of Connector vs Crank Angle

The graph below shows the relation between angular velocity of rocker and crank angle.

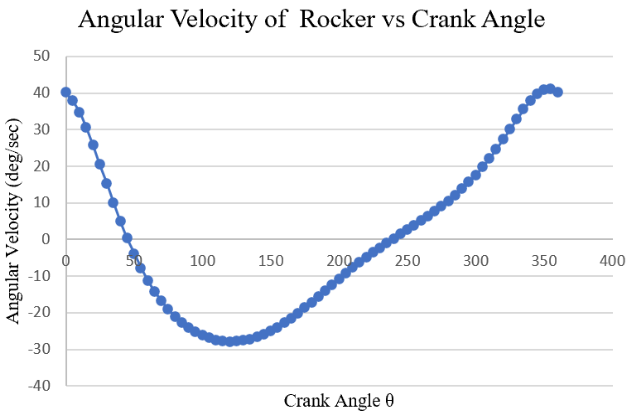

Figure III.4 Angular Velocity of Rocker vs Crank Angle

The figure 4.3 and 4.4 provided depict how the angular velocity changes as the crank rotates about 360 degrees. According to the first figure, the connector experiences a minimum angular displacement of approximately 27.27 degrees at around 130 degrees of crank rotation, at which point it changes direction from counterclockwise to clockwise. Similarly, at approximately 320 degrees of crank rotation, the connector exhibits a maximum angular displacement of 88.7 degrees and changes direction from clockwise to counterclockwise. At the average value of angular displacement of the connector, the maximum velocity is approximately 43.58 deg/sec, and the minimum angular velocity is approximately -31.15 deg/sec. In the second figure, the rocker experiences a minimum angular displacement of approximately 100.34 degrees at around 45 degrees of crank rotation, at which point it changes direction from counterclockwise to clockwise. At approximately 240 degrees of crank rotation, the rocker exhibits a maximum angular displacement of 156.6 degrees and changes direction from clockwise to counterclockwise. At the average value of angular displacement of the rocker, the maximum velocity is approximately 41.08 deg/sec, and the minimum angular velocity is approximately -27.9 deg/sec.

c) Acceleration Analysis

As ω_2 is constant so $\alpha_2 = 0$
By using these formulas and putting all the values in

$$\alpha_3 = \frac{\alpha_2 L_2 sin(\theta_2 - \theta_4) + \omega_2{}^2 L_2 cos(\theta_2 - \theta_4) + \omega_4{}^2 L_4 + \omega_3{}^2 L_3 cos(\theta_4 - \theta_3)}{L_3 sin(\theta_4 - \theta_3)} \qquad 4.6$$

$$\alpha_3 = 0.3320\,\frac{rad}{s^2}$$

$$\alpha_4 = \frac{\alpha_2 L_2 sin(\theta_2 - \theta_3) + \omega_2{}^2 L_2 cos(\theta_2 - \theta_3) + \omega_3{}^2 L_3 + \omega_3{}^2 L_4 cos(\theta_4 - \theta_3)}{L_4 sin(\theta_4 - \theta_3)} \qquad 4.7$$

$$\alpha_4 = 0.3038\,\frac{rad}{s^2}$$

By these formulas and calculations, we get the graphs of angular acceleration for seedling mechanism

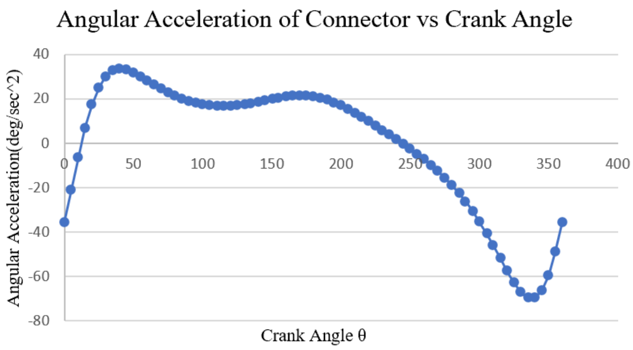

Figure III.5 Angular Acceleration of Connector vs Crank Angle

The graph below shows the relation between angular acceleration of rocker and crank angle.

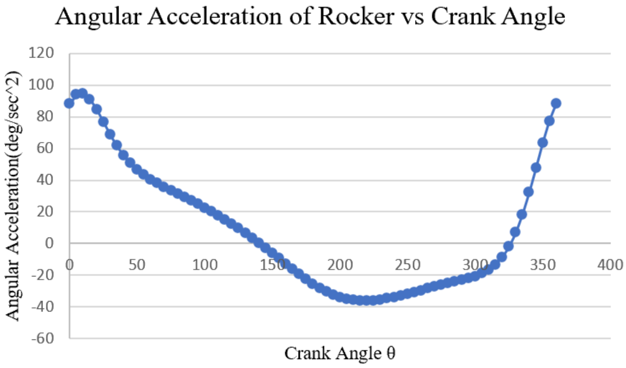

Figure III.6 Angular Acceleration of Rocker vs Crank Angle

The figure 4.5 and 4.6 shows, how the angular velocity changes as crank rotate about 360°. From first figure, we get that when the graph is on positive side than we have acceleration and when it is in negative side than we have deacceleration. In case of connector, we get maximum acceleration of about 33.58 deg/sec^2 and minimum acceleration of about 69.66 deg/sec^2. In case of rocker, we get maximum acceleration of about 94.6deg/sec^2 and minimum acceleration of about 36.2 deg/sec^2.

E. Forces acting on plough

For the force applied on the chisels when in use, Reece's model has found broad adoption[27],[8].

$$\boldsymbol{P_t = \left(\gamma d^2 N_r + cdN_c + c_a dN_c a + qdN_q\right)w} \qquad 4.8$$

The accuracy of soil resistivity prediction using the equation mentioned above relies heavily on the exactness of dimensionless N-factors and the method employed for their computation.

The surcharge pressure, which is the stress, has to be computed in addition to the force. A surcharge pressure has been established by this point, provided there is no water bed.

$$\boldsymbol{Total\ Stress\ = \gamma z} \qquad 4.9$$

$$\sigma_v = (14.34)(0.1)$$
$$\sigma_v = 1.434\text{KPa}$$
$$\sigma = q = 1.434\text{KPa}$$

For the calculation of the forces, some important dimensionless factors were determined, which were later used for the calculation of the forces acting on the plow.

$$\text{Gravity coefficient} = N_y$$

$$Adhesion\ coefficient = N_{ca}$$
$$= \frac{\boldsymbol{-cos}(\alpha + \beta + \varphi)}{(\boldsymbol{sin}\alpha.\boldsymbol{sin}(\alpha + \gamma + \beta + \varphi)} \qquad 4.10$$

$$N_{ca} = 0.907$$
$$Cohesive\ coefficient = N_c$$
$$= \frac{\boldsymbol{cos}\varphi(\boldsymbol{1} + \frac{\boldsymbol{d}}{\boldsymbol{w}}\sqrt{\boldsymbol{cot^2}\ \beta + \boldsymbol{2\ cot}\ \alpha\ \boldsymbol{cot}\ \beta})}{(\boldsymbol{sin}\ \beta.\boldsymbol{sin}(\alpha + \beta + \delta + \varphi))} \qquad 4.11$$

$$N_c = 6.132$$

$$Surcharge\ Pressure\ coefficent = N_q$$

$$= \frac{(\boldsymbol{cot}\ \alpha + \boldsymbol{cot}\ \beta)(\boldsymbol{1} + \frac{\boldsymbol{d}}{\boldsymbol{w}}\sqrt{\boldsymbol{cot^2}\ \beta + \boldsymbol{2\ cot}\ \alpha\ \boldsymbol{cot}\ \beta} + \boldsymbol{sin}(\beta + \varphi))}{\boldsymbol{sin}(\alpha + \beta + \varphi + \delta)} \qquad 4.12$$

After having the dimensionless parameters, the total force acting on the plow by the soil has been calculated below:

$$\boldsymbol{P_t = \left(\gamma d^2 N_r + cdN_c + c_a dN_c a + qdN_q\right)w} \qquad 4.15$$

Furthermore, the total force has been resolved into X and Y components to see how much is exerting on the plow in horizontal and vertical direction.

$$P_h = 0.3289kN$$
$$P_v = 0.027026kN$$

Here are some graphs that show the relation of displacement, velocity and acceleration of plough with respect to time.

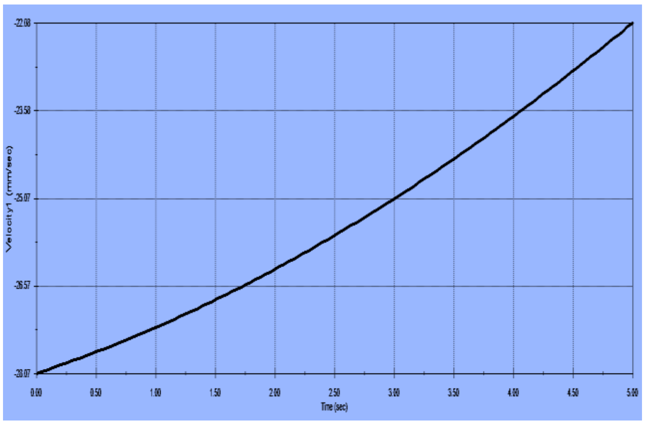

Figure III.7 Velocity vs time graph

The graph 4.8 depicts how the velocity of the plough changes with time. We obtain a negative velocity because we are only observing the y component of its motion, as there is negligible velocity in the x direction.

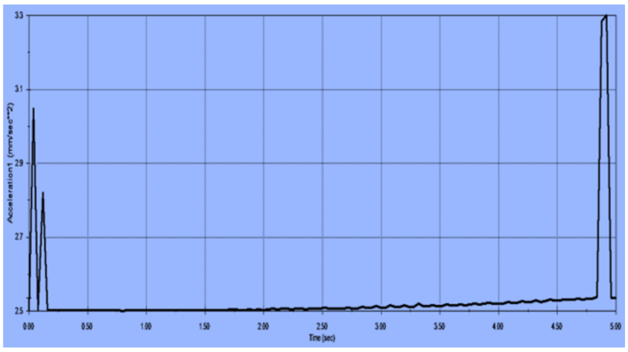

Figure III.8 Acceleration vs time graph

The graph 4.9 depicts how the acceleration of the plough changes with time. From this graph, we can see some peaks at the start and end of this process. These peaks are due to some jerks that occur naturally at the beginning and end of the mechanism.

IV. CONCLUSIONS

The creation and advancement of versatile agricultural robots offer a multitude of benefits to the agriculture sector. They facilitate precision agriculture by employing advanced sensors that optimize farming methods and resource utilization. Additionally, multipurpose agricultural robots tackle labor shortages while also delivering environmental advantages through the automation of repetitive tasks. In summary, these robots are transforming farming practices, rendering them more efficient, sustainable, and productive.

The forces acting on the plough, front roller, and back roller were determined to be 0.04 KN, 1.05 N, and 1.28 N, respectively. The crossed four-bar mechanism is employed for seedling purposes. The connector experienced a minimum angular displacement of approximately 27.27 degrees at around 130 degrees of crank rotation; at that point, it changed direction from counterclockwise to clockwise. At approximately 320 degrees of crank rotation, the connector exhibited a maximum angular displacement of 88.7 degrees and changed direction from clockwise to counterclockwise. For sowing seeds, a rotating drum with a hopper mechanism is used. The successful implementation of this robot demonstrates its potential to revolutionize agricultural practices, providing efficient and precise automation for various farming tasks.

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