Design of Variable Rate Fertilizer Spreader for UAV

A Final Year Project Report

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of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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Spreader for Agri Drone

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ABBREVIATIONS

DEM	Discrete Element Modelling
VRF	Variable Rate Fertilization

NOMENCLATURE

Φ_d	Orifice Opening
T_r	Required Torque
I_d	Disc moment of Inertia
w_{accu}	Accumulated Sample Weight
d_{pr}	Proximity from disk spreader

ABSTRACT

Precision Agriculture is a term which is widely used in the current 21^{st} century, it means to implement the modern technologies, especially modern computing, artificial intelligence, satellite communication and drone technology to increase the agriculture productivity and decrease the cost. Variable Rate Fertilization (VRF) is a part of this whole ecosystem, and it is one of the multiple steps, like satellite mapping and drone technology. Variable Rate Fertilization means to spread fertilizer at a desired rate, according to the data given to it. VRF technology is implemented with the help of device called as the Variable Rate Fertilizer Spreader and in this paper, we have discussed the whole process from concept design to the methodology and results and discussions of the variable rate fertilizer spreader. This technology is a very important part of the whole ecosystem, and it lies at the end of the whole ecosystem, where all the data communicated is fed to the device and variable fertilization is achieved as an output. Crop growth is the main part of all the agriculture, and it's been for the time when the human civilization learned to first plant the wheat. Crop growth is directly proportional to the yield of the crop, which is directly linked to the food supply of the humans. When there is multiple harvesting at the same area, the soil lacks the nutrients because of cyclic harvesting and planting. So, fertilizer comes into play where at the end of each harvesting and at the start of the planting and during the different growth stages of the plants, it is fed into a specified and calculated quantity to the crop. Due to the increase in the food supply of the humans, agriculture done on large areas and manual fertilizer spreading is inefficient and results in the loss of the money and inefficient plant growth. So along with all the sophisticated technologies, such as the satellite mapping, drone technology and artificial intelligence, we collect data and knows that how much amount of the fertilizer is need for the specific area of the crop. Our device, variable rate fertilizer spreader can spread the fertilizer at the desired amount and it is attached to the drone and can work 24/7, thus increasing the efficiency and resulting in low-cost operations and decreasing the use of the manpower and increasing the time management.

CHAPTER 1: INTRODUCTION

Problem Statement

Precision Agriculture encloses a very sophisticated technology of Variable Rate Fertilization (VRF) which means to supply the fertilizer to crops at a calculated amount as according to the received data through Precision Mapping and Global Positioning System.

In this project we have to design a Variable Rate Fertilizer capable of spreading fertilizer at a required quantity, to the crops.

Objectives of the Project

Efficient Crop growth is highly dependent upon the right amount of fertilizer given to the crop which ensures the right amount of nutrients given to the crop. Our goal is to design a Variable Rate Fertilizer Spreader that is capable of spreading the right amount of fertilizer as the data given by the higher systems.

Motivation of Work

Pakistan is a agricultural country and more than 70% of the population of our country specifically youth is linked with the agricultural sector. Pakistan has one of the fertile lands in the world but its agricultural output is very low as compared to the other countries, due to the lack of precision agriculture technology in our agricultural sector.

Variable Rate Fertilization (VRF) is an important part of this whole precision agricultural ecosystem.

Our goal is to design this variable rater spreader to contribute in the goal of implementing precision agriculture technology in our agriculture sector which has a huge potential.

CHAPTER 2: LITERATURE REVIEW

Based on our literature review and findings, there are two major categories of fertilizer spreaders. These are air assisted or pneumatic and centrifugal spreaders which are discussed in detail below:

Note: Both the spreaders discussed below were designed for seed spreading at uniform rate. But these papers gave insight view on how the whole thing should work. Our work is based on these findings which we changed in our accordance. These spreaders can be modified to spread fertilizer at variable rate

Air-Assisted Spreader

Air-Assisted or pneumatic spreader is shown below:

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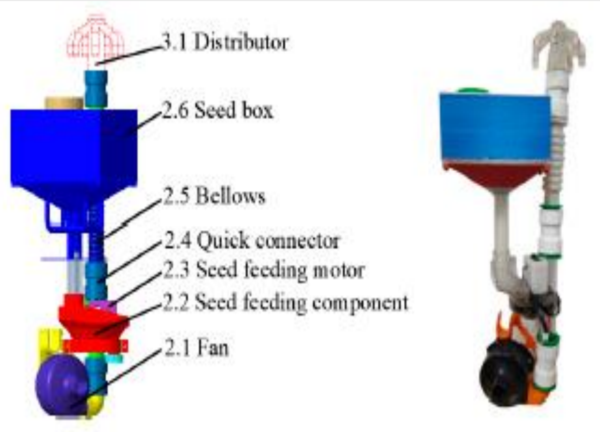


Figure 1:Air Assisted Spreader

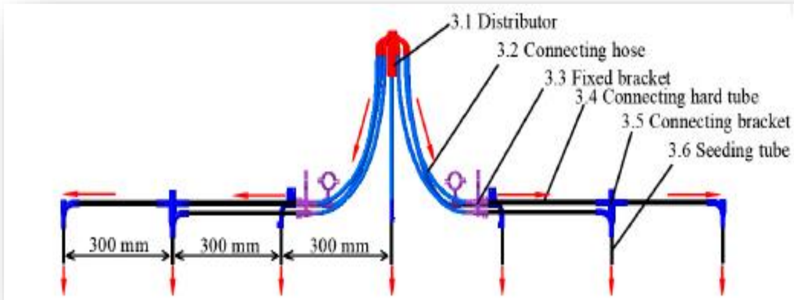


Figure 2: Pneumatic spreader

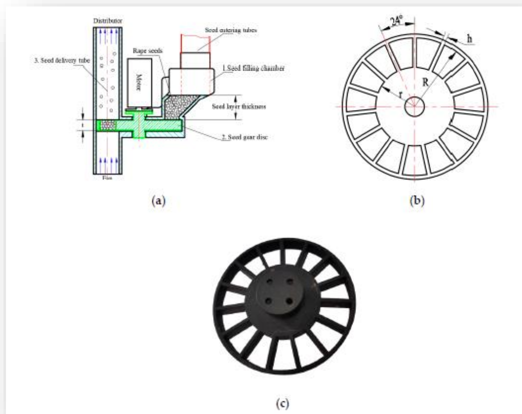


Figure 3: Spreader Schematic

The working mechanism of this spreader can be divided into four main steps: seed filling, seed carrying, seed cleaning and seed dropping. The seed disc transfers the seeds continuously and quantitatively from the seed chamber to the vertical tube. After the seeds are in the vertical tube, they are made to move along the channels via air flow until they are thrown out of the system. In the process of moving upwards, air pressure must overcome the gravity of seeds and resistance force of the channel flow.

Centrifugal Spreaders:

The spreader under discussion here was designed for spreading seeds and it contains baffle ring around the rotating disc as spreading mechanism. The centrifugal seed spreader is composed of seed box a feeding unit and rotating disc a spreading unit. The seeds drop on the rotating disc under the action of gravity and rebound at baffle ring thus spreading the seeds. As the seeds move towards the edge of the disc, they will experience the frictional force from disc, thrust from vanes and Coriolis force. The seeds will be ejected from the disc and rebound on the baffle ring. The schematic diagram of such spreader is shown below:

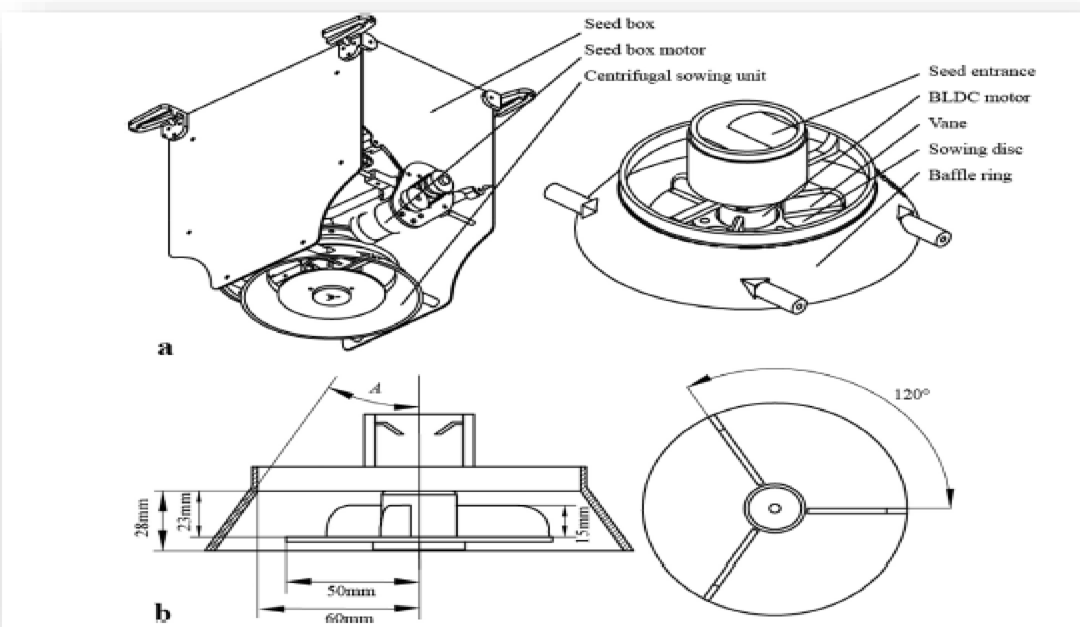


Figure 4: Disc based Centrifugal spreader

Selected Type:

We selected the centrifugal type of spreader because of the following reasons: In air assisted spreader, air pressure is used to overcome the gravity and move the seeds up the channels. The fertilizers are heavier in weight so they require greater air pressure which will consume more power and heavy pump which is not feasible for UAV system. Secondly the air assisted system is more complex and we have less control over the motion of particles. Owing to these reasons, we have chosen the centrifugal spreader. Centrifugal spreader has less moving components and we have significant control over the motion the particles. The designs that have been developed by us so far are shown,

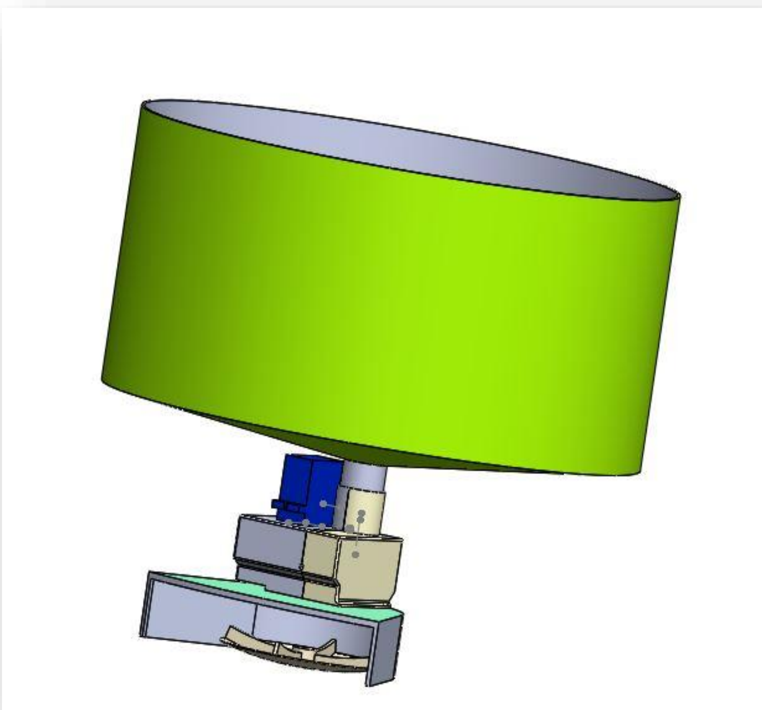


Figure 5: Design 1

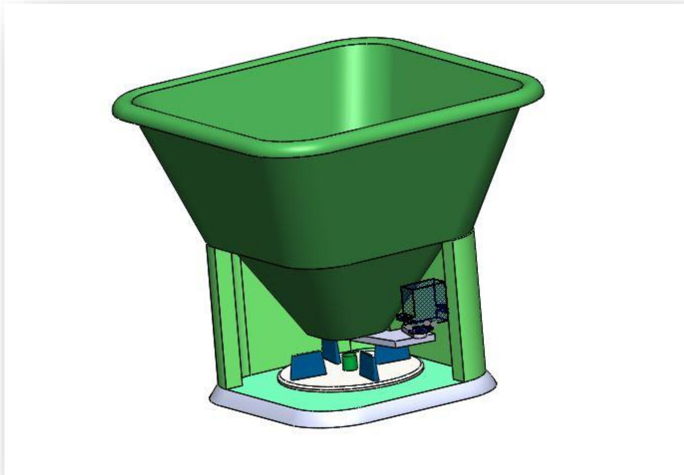


Figure 6: Design 2

Disc Properties:

Next, we discuss the different disc characteristics such as vane numbers, vane height and van shape. The distribution pattern of the rotating disc spreaders is affected by flow perimeters, physical and chemical properties of fertilizer, and the design of the disc. For this section different research papers were consulted related to the motion of the particle on rotating disc and the parameters effecting the motion.

Vane Height:

To see the effect of vane height on the distribution of fertilizers on rotary disc spreaders, an experiment was carried out in which different vane heights were tested against different flow rates and results were obtained. The fertilizer was made to run through orifice of fixed diameter and fall onto the disc under the action of gravity. The fertilizers used in the experiment are triple superphosphate and calcium ammonium nitrate. Following vane was used in the experiment:

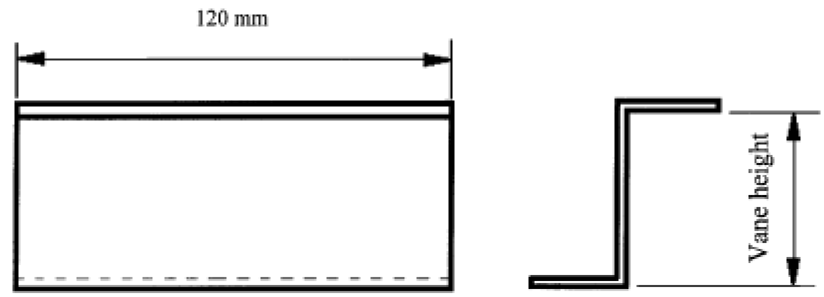


Figure 7: Vane Height

Following are the valuable results that were obtained from the experiment:

- The most uniform distribution was obtained by the vane height of 35mm along with the orifice diameter of 35mm.
- For triple superphosphate, mean CV values varied between 7% and 20% and variation of CV value was least with vane height of 65mm.
- For calcium ammonium nitrate, mean CV values varied between 6% and 17% and variation of CV value was least with the vane height of 45mm.

Vane Number:

To see the effect of vane numbers on the distribution of fertilizer, same experiment was conducted with the difference that the vane height of 65mm was used for triple superphosphate, and for calcium ammonium nitrate, vane height of 45 mm was used. Disc was rotated at 540 rev/min and following results were obtained:

Vane Number × Orifice Diameter (mm)	Skewing[b] (%Left/%Right)	CV (%)	Minimum[c] (%)	Maximum[c] (%)
2 × 30	50/50	11 i[d]	76	122
2 × 40	45/55	17 gh	74	131
2 × 50	46/54	20 f	68	131
4 × 30	45/55	15 h	78	127
4 × 40	43/57	23 e	68	150
4 × 50	43/57	26 de	63	143
6 × 30	46/54	16 h	71	148
6 × 40	42/58	26 de	67	155
6 × 50	40/60	31 bc	59	160
8 × 30	46/54	19 fg	67	141
8 × 40	45/55	28 dc	48	153
8 × 50	43/57	32 ab	58	159
10 × 30	46/54	19 fg	71	140
10 × 40	39/61	30 bc	66	166
10 × 50	40/60	34 a	60	163
12 × 30	43/57	20 f	72	144
12 × 40	51/49	26 de	59	143
12 × 50	43/57	34 a	57	157

Vane Number × Orifice Diameter (mm)	Skewing[b] (%Left/%Right)	CV (%)	Minimum[c] (%)	Maximum[c] (%)
2 × 30	48/52	10 k[d]	84	116
2 × 40	45/55	16 ij	77	127
2 × 50	46/54	22 gh	72	148
4 × 30	49/51	14 j	82	120
4 × 40	45/55	20 h	74	139
4 × 50	47/53	24 fg	61	144
6 × 30	46/54	16 ij	80	130
6 × 40	48/52	24 fg	69	147
6 × 50	42/58	28 de	66	164
8 × 30	45/55	19 hi	76	140
8 × 40	43/57	29 cde	67	156
8 × 50	42/58	32 abc	65	174
10 × 30	47/53	26 ef	69	150
10 × 40	43/57	28 de	71	156
10 × 50	44/56	33 ab	66	160
12 × 30	44/56	26 ef	65	148
12 × 40	44/56	30 bcd	71	153
12 × 50	46/54	35 a	64	165

Figure 8:Experimental data for varying Vane number and Orifice Diameter

CHAPTER 4: RESULTS AND DISCUSSIONS

Till now following results are concluded after reviewing all the literature and doing all the necessary calculations, but final and complete results are in the way and will be calculated when the project is finalized.

Disc Dimension Optimization:

Spreading disc is an integral part of our design. It plays a major role in even distribution of fertilizer and spread pattern. The dispersion characteristic of disc is very much dependent on its dimensions and vane configuration. So, for application of fertilizer on a farm as per specification or area specific application it is necessary, we use Mathematical modelling, Simulation studies and experimental results. Although we can't use advanced techniques because of equipment cost which could enable us to effectively pre-set these parameters yet we can use experimental results to tweak some of the control parameters.

Spreader Disc Design:

To optimize the Disc Dimensions, we firstly, need to define the design parameters. Following are the design parameters which are taken into consideration for deciding on disc dimensions.

Design Parameters:

1. **Motor torque specification (T_r)**:

The torque obtained by the excel sheet calculation is **0.003450554[Nm]** for the current design configuration depicted in Table 1. Additional Torque will be required considering feed rate, particle density and drag on vanes but these factors have can be neglected if we assume lower feed rate and use lower value for RPM.

2. Spread radius:

Spread radius depends on fertilizer properties, spreader disk configuration and Disk RPM. The most effective and easy way to control the spread radius is by controlling RPM and it can be tweaked according to a specific application based by testing

3. Feed orifice position/Feed Gate position:

The feed orifice @ 45 Degree position angle for site specific application[1].

4. Spread pattern:

Spreader spread pattern or distribution profile depends on many factors some of the major ones are mentioned here.

i. Angular velocity of disc affects the spreading width greatly.

ii. Also position of orifice w.r.t traverse direction if it is at 45 degrees the spreading is better[13]. It affects the distribution pattern.

iii. Orifice Opening ϕ_d also plays an important role.

iv. The angle of the segment shaped orifice opening, have a large influence on the shape and width of the spread pattern.

Disc Dimensions/ Base Design Optimization:

Disk Configuration:		Design Units	SI [m]
Disk Diameter:	100	mm	0.12
Disk thickness	4	mm	0.004
Volume of disk:	3.14159E-05	m^3	

Disk mass	0.033615041	Kg	

Vane Configuration:

		Design Units	SI [m]
Vane Type: Forward curved			
Vane curvature Chord Length (1/2*Disk R):	30	mm	0.03
Vane height:	10	mm	0.01
Number of vanes:	4	(90-degree placement angle)	
Vane curvature lateral extent	5	mm	0.005
vane thickness	2	mm	0.002
Volume of each vane:	0.0000006	m^3	
Individual vane Mass:	0.000642	kg	

Table 1: Finalized Vane Configuration

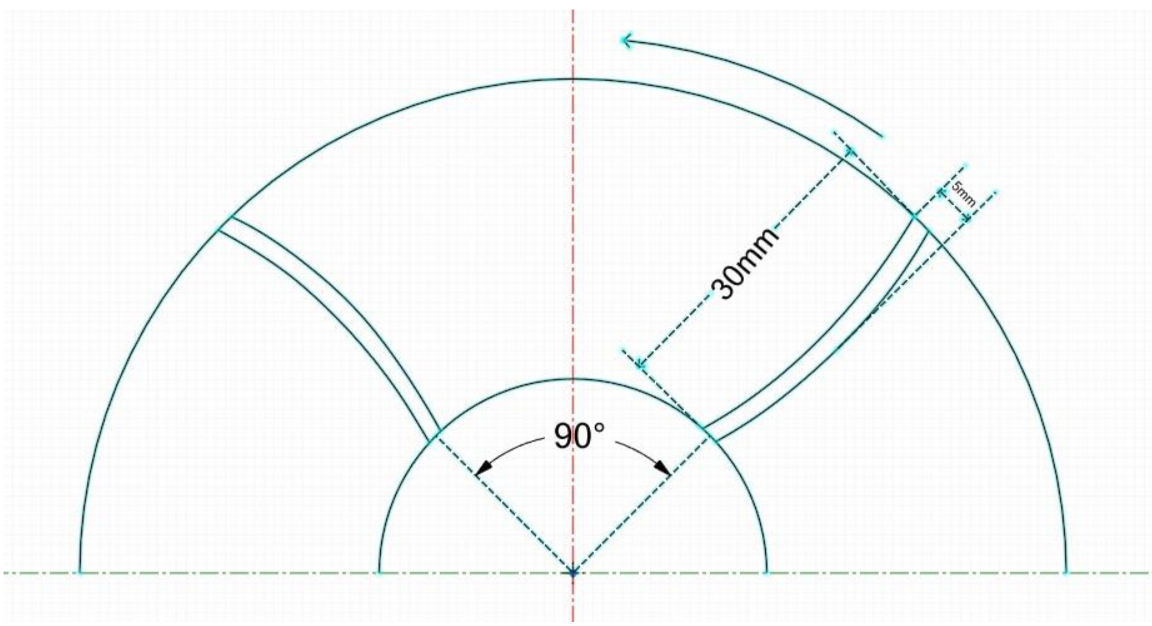


Figure 9:Forward curved vane config with 5 mm curvature lateral extent

Along with Dimensions from Optimization studies, forward curved configuration is chosen because it has less CV values and is less skewed to either side (more even distribution) [1]

Calculations:

Model Calculation for determining Torque:

Disk Diameter= $\Phi = 120mm = 0.12m$

Disk Thickness= $t = 4mm = 0.04m$

Disk Volume= $v = 4.524E - 5m^3$

Material density (ABS)= $\rho = 1070kg/m^3$

Number of vanes: 4

Vane Height= $10mm$

Vane thickness= $2mm$

Vane curvature lateral extent= $5mm$

Note: The values of design dimensions above are the finalized values obtained after an optimization study done in excel considering various design objectives explained under design parameter heading.

Disk mass= $m_d = \rho v = 0.04840566Kg$

Similarly,

Individual vane mass = $m_v = 0.000642$Kg

Now,

Total Moment of inertia (About motor axis) $= I_d + 4I_v = \frac{1}{2} * m_d * R^2 + 4 * [\frac{1}{2} * m_v * (C_l^2 + C_w^2) + m_v * d_{vane\ center}^2] = 6.59\text{E} - 05 Kg.m^2$

Angle acceleration from 0→1500R PM (157rad/s) in 3= $\frac{\omega_f - \omega_i}{t} = 52.36 rads^{-2}$

Torque required for motor to accelerate to 1500RPM in 3 sec= $I_t * \alpha =$ ***0.003451*** *N.m*

Note: The calculated moment of inertia is verified from solid works after creating a 3D model with same disk dimensions and the percentage error turns out to be **0.00004%.** The value of torque is now Decent enough, and we have decent lower weight motor options to be able to rotate the disk as per our requirements and have better control.

Type of Fertilizer Spreader:

We selected centrifugal fertilizer spreader due,

1. Light weight design.
2. Less complex design.
3. Usage of only one motor with no blower as compared to the pneumatic design.
4. Easy to assemble and repair.
5. Less expensive design as compared to pneumatic one.
6. High durability of the parts.
7. Have fewer moving parts.

Selection of Control System:

We selected the following control system,

1. Use of Esp32 microcontroller having Bluetooth and Wi-Fi module.
2. Programming using Arduino IDE.
3. Use of a BLDC motor to rotate the disc.
4. Use of the servo motor to run the flow rate control mechanism.
5. Use of open source Blynk application, to control the system remotely.

Control System:

The Control system is the most essential part of the process of the fabrication of a project. As discussed earlier, we have the following deliverables in our project.

1. To achieve a Variable rate of fertilizer, throw from the hopper on the disc.
2. To control the rpm of the disc, to control the throw of the fertilizer.

To achieve a Variable Rate:

Variable Rate was achieved, by varying the orifice diameter of the hopper. The diameter was varied with the help of a disc, as shown below in the figure.

Figure 10: Variable Flow Rate Disc

The disc has three orifices of varying diameter, and through all of these, offices the flowrate of the fertilizer can be varied by controlling the amount of the fertilizer flowing through the disc.

Variable-rate was achieved through a servo mechanism, that was controlled through the servo motor and the servo motor was controlled through the potentiometer, that sent a signal through the Nrf24l01 module, which will be explained later, below is the image of the servomechanism assembly, schematics, and the circuit diagrams will be explained later.

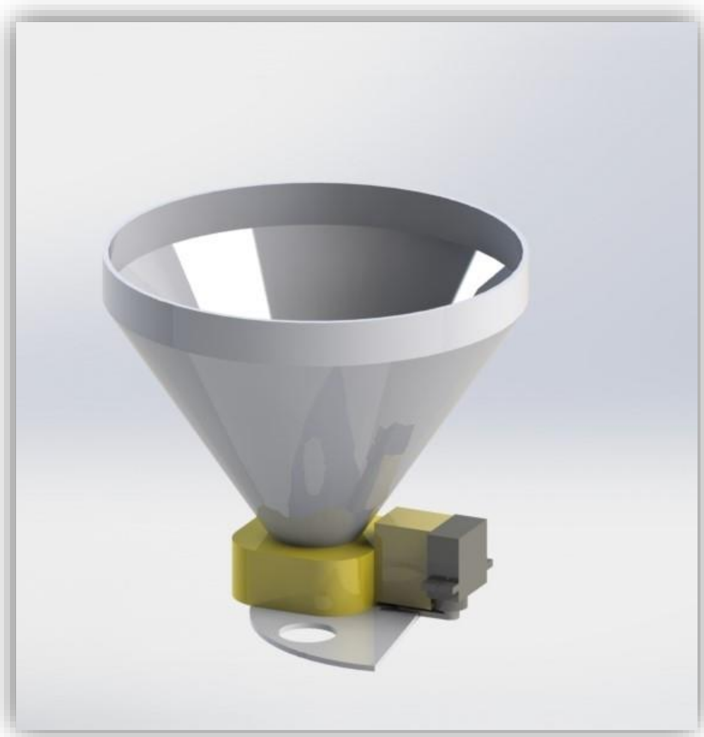


Figure 11: Flowrate Control Assembly

The servo motor is attached to the disc, and it can rotate the disc, at the angles of 45 degrees increment and can change the orifice diameter, more detailed view for a better understanding is provided below, which shows the flow rate changing and changing of the or orifice diameter.

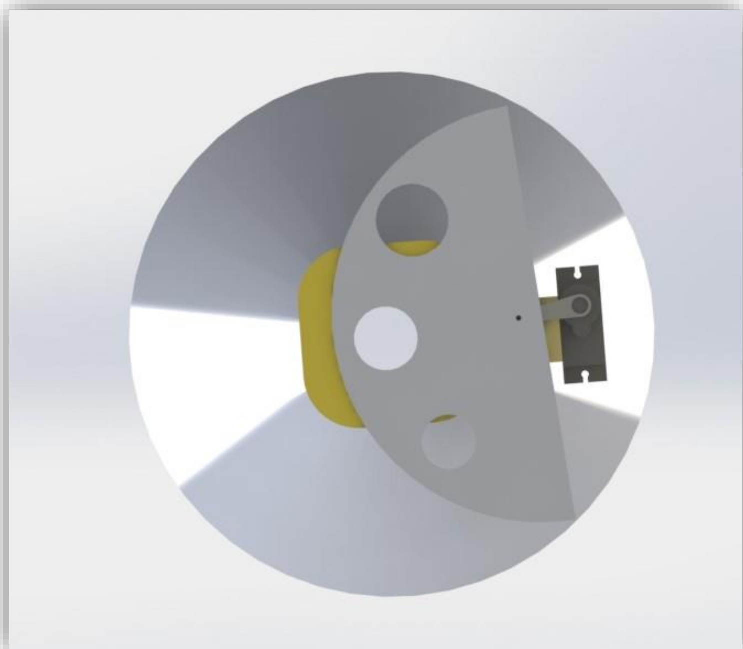


Figure 12: Flowrate Control Assembly, Bottom View

Now we can have a better estimation of how the office diameter changes, with the help of the servo motor moving at the incremental angles. It changes the orifice diameter and hence changes the amount of fertilizer flowing through the holes. A more zoomed-in view is provided below, to have a much better visualization of the mechanism.

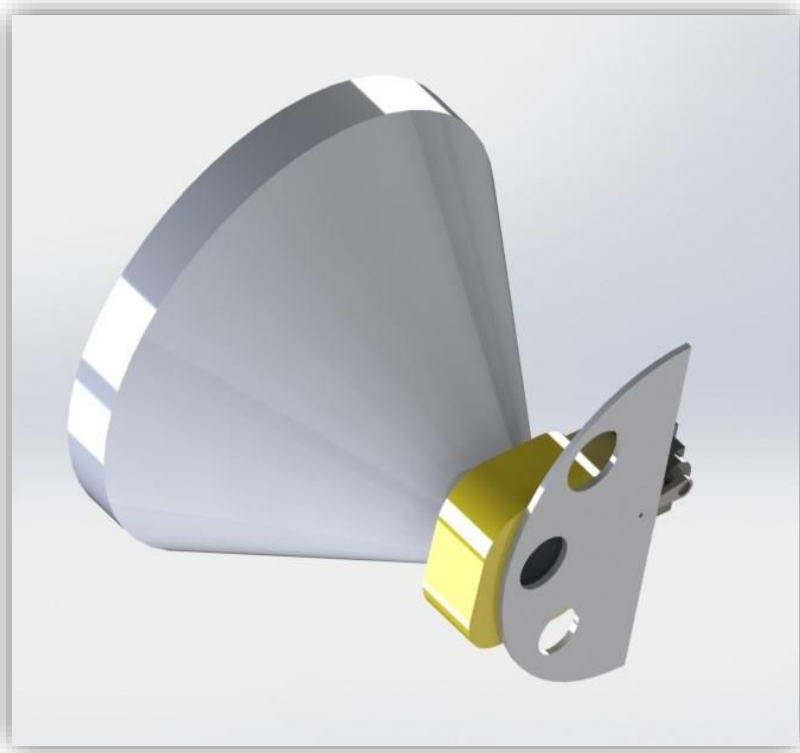


Figure 13: Flowrate Control Assembly Close View

To control the Rpm of the Disc:

Controlling the rpm of the disc is influencing the spread range of the fertilizer, that how far the fertilizer goes, it was due to the centrifugal force that was exerted on the particles, by colliding through the vanes of the fertilizer spreading dis, More is the rpm of the disc, more force will be exerted on the particles colliding on the disc and hence farther they will go, which in turn ill increase the spread radius of spread range of the fertilizer throw. Fertilizer throw is directly related to the target crop or the target radius. As discussed above that to keep the spread throw optimal, we must test it in the field and decide the optimal range of the fertilizer throw pattern, hence the disc RPM.

Optimum rpm of the Spreading Disc:

So, through the field testing in the field, after observing the optimum fertilizer range, we decided on the optimum rpm of the spreading disc which is 1400 rpm to 1600 rpm.

There were multiple field tests carried out in different locations, to verify the fertilizer spread pattern and adjust the rpm of the fertilizer to have the optimum and a defined range. Basically, here the optimum range is important as in the real-time the three must be a target group of crops where the fertilizer has to be spread and at a defied rate, the rate as told earlier the defined rate can be achieved through the changing of the orifice diameter and through the servo mechanism. So, to adjust the throw, as mentioned earlier we varied the rpm of the disc, some of the images of the multiple grids are shown below in the figure, where we can see that there are two sizes of the grid, one is horizontal and long, and another one is like a triangular grid. So, we are adjusting the rpm of the disc to adjust the fertilizer in the grid.

Variable Rate Mechanism:

As all the background explained earlier, now e will discuss how the rpm is varied as in the case of the variable flow rate the flow rate mechanism, is controlled by the servo motor, and the rpm is controlled by the Bldc motor. Some images of the bldc mechanism are shown below it is an assembly of Bldc motor long with the spreader disc, we will talk about the components in detail.

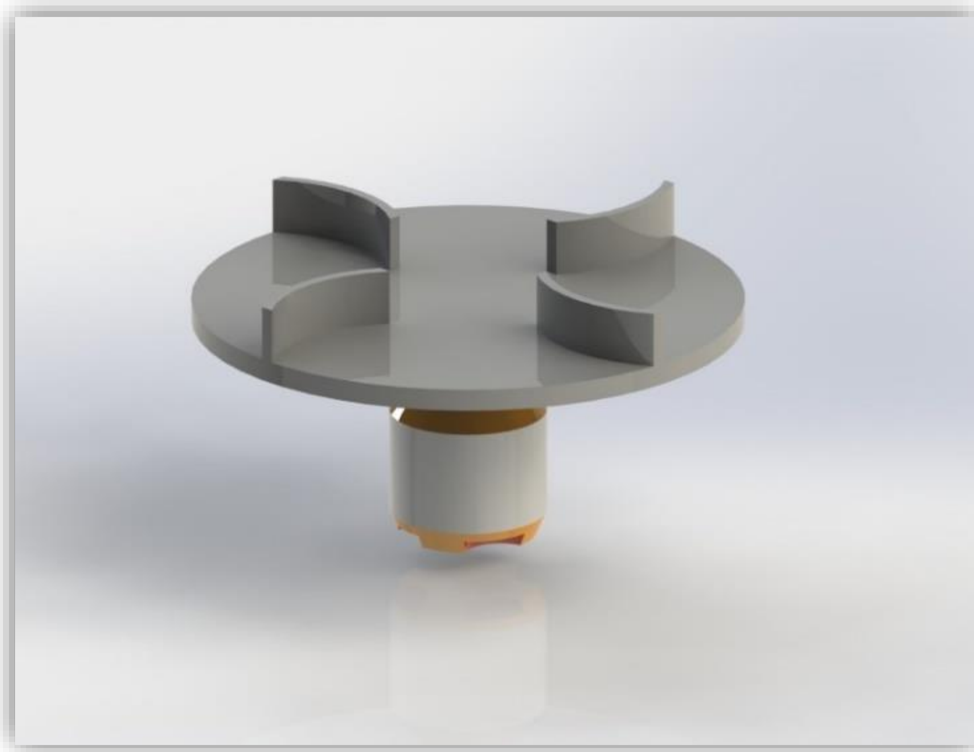


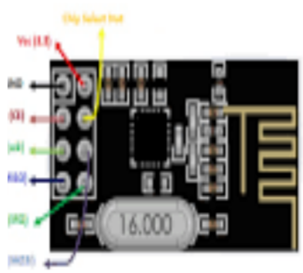
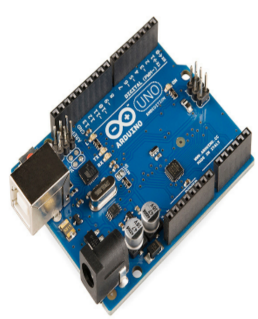
Figure 14: Rpm Varying Mechanism

Electronic Components Description:

Electronic components make up the control system and the selection of these components is very important as they form the whole control system that executes the task. Our control system consists of a microcontroller and various motors. We had dived the control system into two parts, one is a transmitter and the other one is the receiver, more detail will be given bout them below.

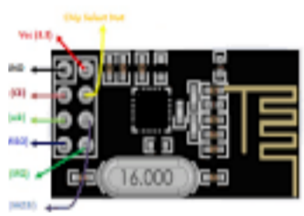
Following electronics components were used,

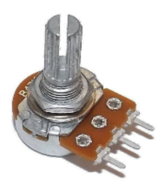
NAME	PICTURE	Description
Bldc Motor		Bldc motor is a lightweight motor best for variable rpm range and works on PWM signal
Servo Motor		Servo Motor is used for the precise measurement in angles and it is light weight.it also works on the PWM signal, where varying the rpm conntrols the voltage.
Potentiometer		Potentiometer is a analog device, that gives values from 0 to 1023, where 0 stands for the 0 volts and 1023 stands for maximum voltage of your battery, in our case it was 7,4 volts

NAME	PICTURE	Description
Arduino Uno		Arduino Nano is a small microcontroller, that is lightweight and suitable for our assemblu. It is based on Arduino IDE
nRF24L01 Module		nRF24L01 modu;le is a transceiver that can be used as a transceiver and receiver. It works on RC signal.
Arduino Uno		Arduino Uno is a microcontroller, it is larger then Arduino Nano, but still Light weight. It works on Arduino IDE platform.

Electronic Components Function:

As we have explained the electronic parts used, now we will describe their function in our control system and the execution of the project.

NAME	PICTURE	Function
Arduino Uno		Arduino Nano is in the receiver part, as it is light weight and it controls the receiver, Bldc Motor and Servo Motor
nRF24L01 Module		nRF24L01 is used as both transmitter and the receiver, i is used for distance communication.
Arduino Uno		Arduino Uno is used in the transmitter part and it is used to control the transmitter and the potentiometer.

NAME	PICTURE	FUNCTION
Bldc Motor		Bldc motor is used to vcontrol the rpm of the fertilizer spreding disc, in this way we can control the spraed range of the fertilizer
Servo Motor		Servo motor was used to control the flow rate by incrementing the angles, on the principle of Pulse Width Modulation, it is attacheed to the flow rate disc.
Potentiometer		Potentiometer generates the analog signal from vallues 0 to 1023, so we can vary the voltage and execute the Pulse Width Modulation for both Bldc Motor and the Servo Motor.

Depiction of the Transmitter and Receiver Mechanism:

As we have to control our variable rate spreader remotely, and one part of the variable rate spreader is attached to the drone and the other part is on the ground so we use a transmitter and the receiver mechanism in our variable rate spreader is on the drone, so we used a transmitter receiver-based mechanism which is executed through the Nrf24L01 module and it can act as both the transmitter and the receiver, depending on the code, used we will explain the schematics and the circuit diagrams later, but first below is the depiction of the variable rate spreader mechanism with transmitter and the receiver, and nRF24L01 module acts as the transmitter on the one side and the receiver on the other side.

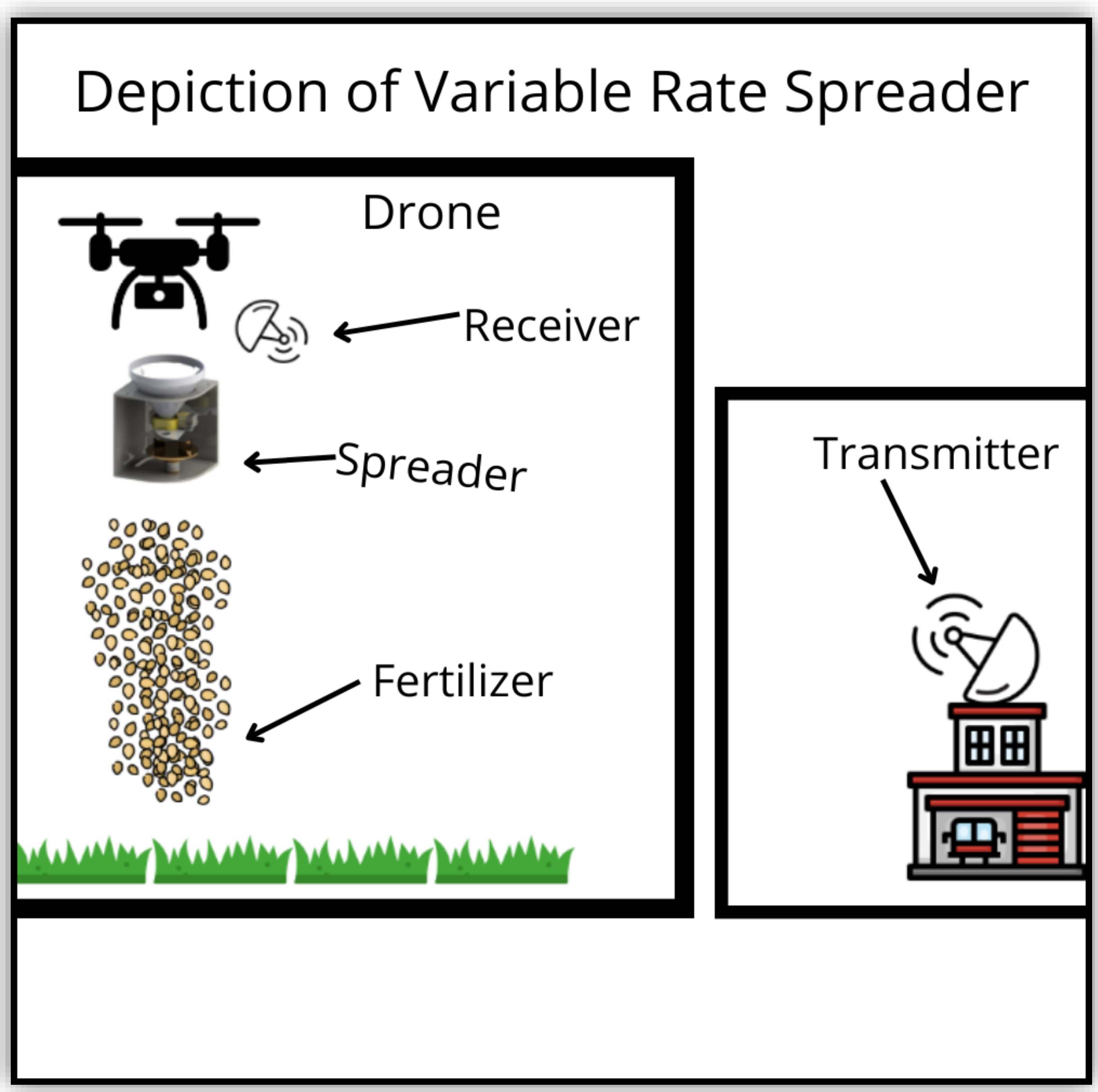
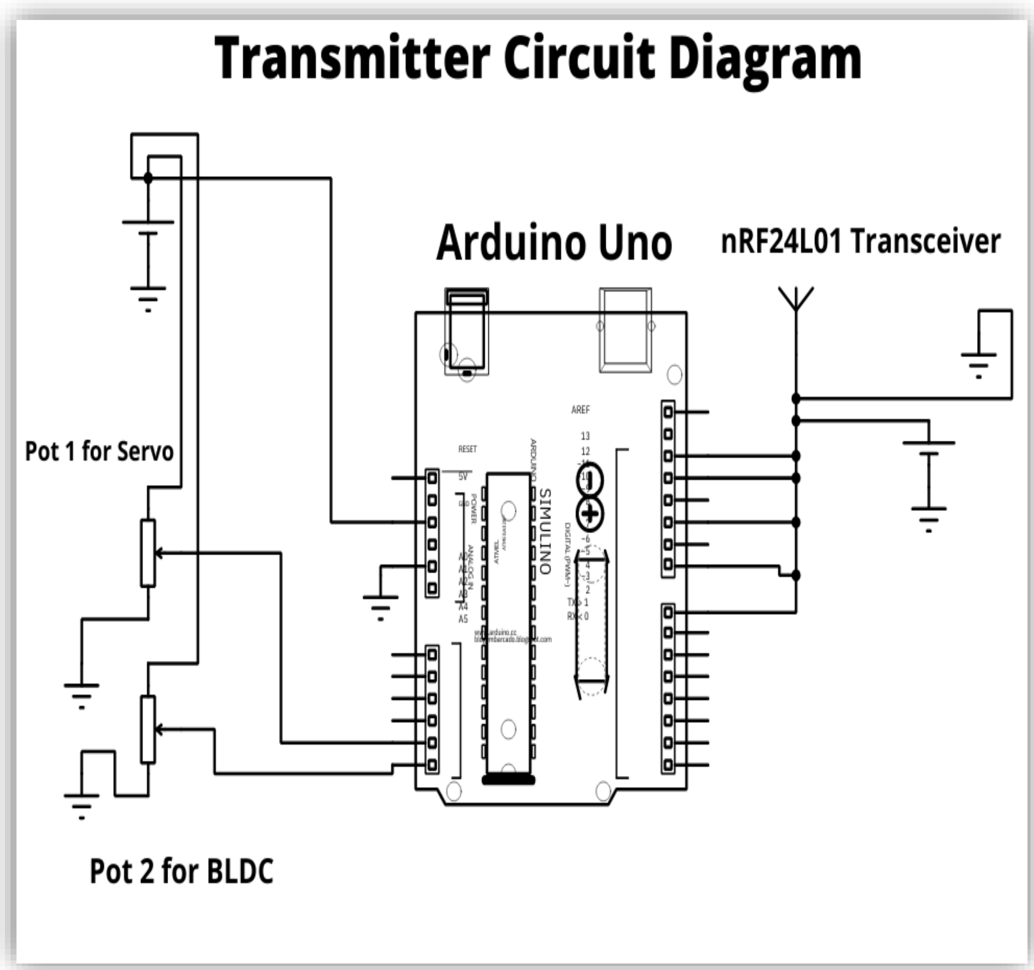


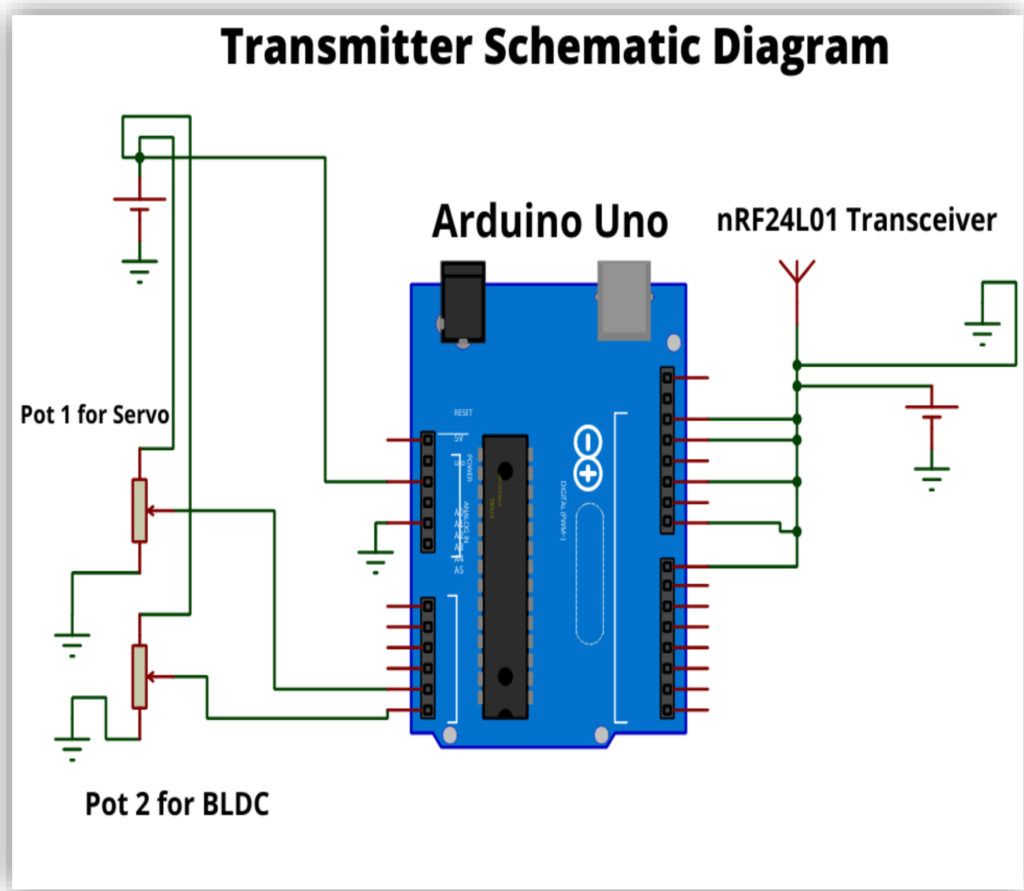
Figure 15: Depiction of Variable Rate System

Schematics and Circuit Diagrams:

Transmitter:

Below is the schematic and the circuit diagrams of the transmitter part.





As explained earlier, transmitters consist of Arduino Uno along with a potentiometer which is the analog device and can generate the analog values from 0 to 1023, 0 stands for the 0 volts, and 1023 stands for maximum battery voltage. An Nrf24l01 module is connected to the Arduino Uno and here it acts as the receiver. It transmits the RC signals and communicates to the other part of the spreader that is attached to the drone and is explained below.

Code for Transmitter:

Below is the code for the transmitter part.

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>

const uint64_t pipeOut = 0xF9E8F0F0E1LL;   //IMPORTANT: The same as in
the receiver 0xF9E8F0F0E1LL

RF24 radio(7, 8); // select CE,CSN pin

struct PacketData
{

  byte lPotValue;
  byte rPotValue;

};
PacketData data;

void setup()
{
  radio.begin();
  radio.setDataRate(RF24_250KBPS);
  radio.openWritingPipe(pipeOut);
  radio.stopListening(); //start the radio Transmitter


}



void loop()
{

  data.lPotValue      = map(analogRead(A5), 0, 1023, 0, 254);
  data.rPotValue      = map(analogRead(A6), 0, 1023, 0, 254);

  radio.write(&data, sizeof(PacketData));
}
```

Figure 16: Transmitter Code

The code starts with the initial standard lines that enable the transceiver to act as the transmitter and whatever it reads the data from the potentiometer from the analogRead command it converts it into the signals, RC signals, and sends it to the Receiver.

Receiver:

Below are the schematics and circuit diagrams for the receiver.

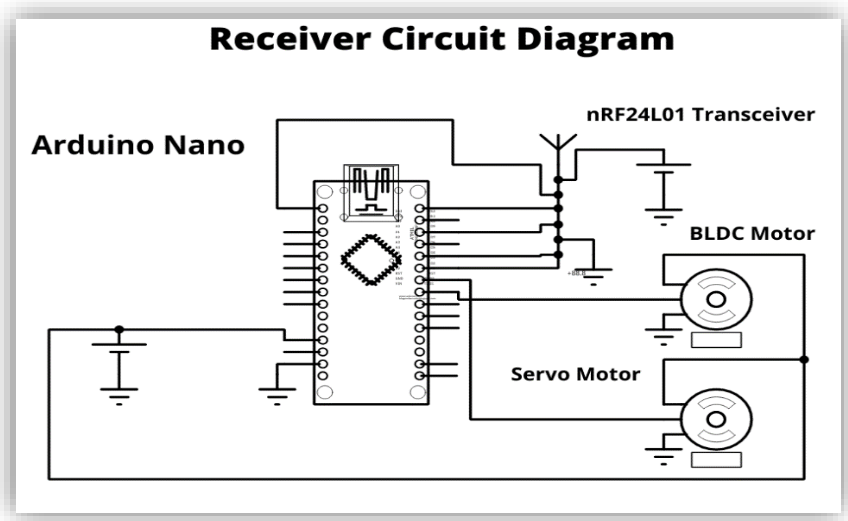


Figure 17: Receiver Circuit Diagram

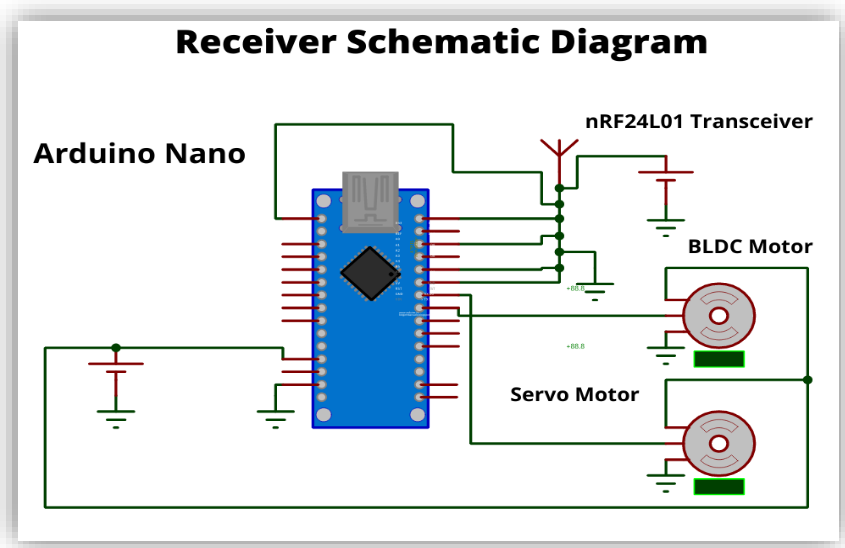


Figure 18: Receiver Schematic Diagram

Above are the schematics and the circuit diagrams of the receiver and, we have Arduino nano which is connected to the Bldc motor and the Servo motor. Arduino nano is also connected to the transceiver module, which acts as the receiver. The receiver receives the signals from the transmitter and fed the values to the Arduino nano.

Arduino nano maps the analog values to the digital values, and they are fed to the servo and Bldc motor.

Below is the code for the receiver part,

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <Servo.h>

#define SIGNAL_TIMEOUT 500  // This is signal timeout in milli
seconds. We will reset the data if no signal

const uint64_t pipeIn = 0xF9E8F0F0E1LL;
RF24 radio(7, 8);
unsigned long lastRecvTime = 0;

struct PacketData
{

  byte lPotValue;
  byte rPotValue;

};
PacketData receiverData;

Servo servo1;
Servo ESC;


//Assign default input received values
void setInputDefaultValues()
{


  receiverData.lPotValue = 0;
  receiverData.rPotValue = 0;
}

void mapAndWriteValues()
{

  servo1.write(map(receiverData.lPotValue, 0, 254, 0, 180));
  ESC.write(potValue);
```

```
  ESC.write(potValue);



}

void setup()
{
  radio.begin();
  radio.setDataRate(RF24_250KBPS);
  radio.openReadingPipe(1,pipeIn);
  radio.startListening(); //start the radio receiver

  servo1.attach(5);
  ESC.attach(6,1000,2000);


  setInputDefaultValues();
  mapAndWriteValues();
}

void loop()
{
  // Check if RF is connected and packet is available
  if(radio.isChipConnected() && radio.available())
  {
    radio.read(&receiverData, sizeof(PacketData));
    lastRecvTime = millis();
  }
  else
  {
    //Check Signal lost.
    unsigned long now = millis();
    if ( now - lastRecvTime > SIGNAL_TIMEOUT )
    {
      setInputDefaultValues();
    }
  }
  mapAndWriteValues();
}
```

Figure 19: Receiver Code

Experimental Results:

Experimental Setup:

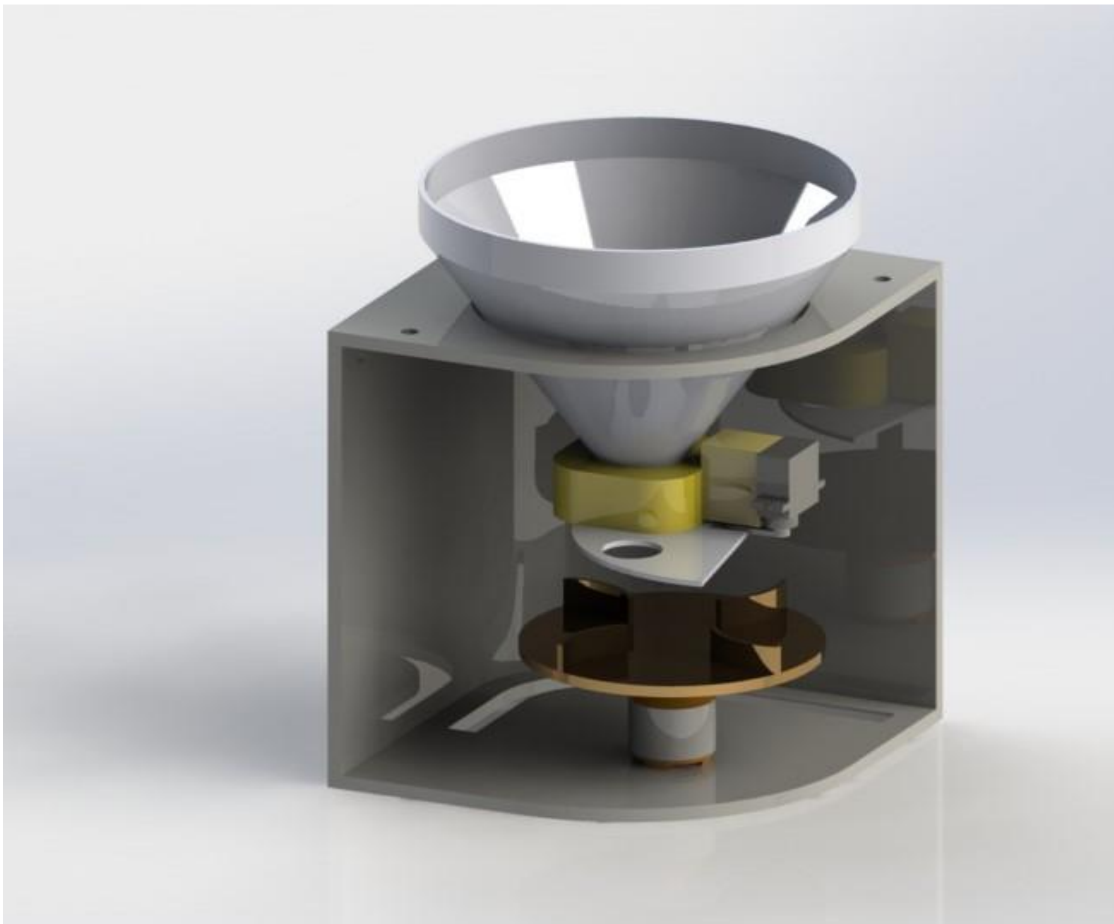


Figure 20: Final Prototype assembly without hexacopter

The picture above shows the prototype we fabricated for our experimentation. The hopper has a capacity of 200 grams. A semi-disk with 3 holes of varying diameter is used to control the feed which is **actively** controlled by a motor. To determine the application rate of the fertilizer, a time run time of 10s is used for each hole size which also coincides with the time it takes to empty a filled container when engaged with the largest disk hole. The control variables of our system are RPM and hole size where latter varies the flow rate of fertilizer in a specific flight condition.

Feed rate control:

As mentioned earlier, the feed rate is control when the hopper end is engaged with a specific hole in the disk. The semi-disk is actively controlled to change the feed rate as per our requirements by effectively changing the opening diameter as a specific disk hole engages with the hopper. Here we only considered the distribution pattern and fertilizer flow rate. Given below are picture depicting the fertilizer feed rate control. In each figure below the trial run time is consistent at 10s where figure 11,12 and 13 corresponds to Opening diameter of 2,1.75 and 1.5cm respectively.

Figure 21: Fertilizer distribution for opening diameter @2cm

Figure 22: Fertilizer distribution for opening diameter @1.75cm

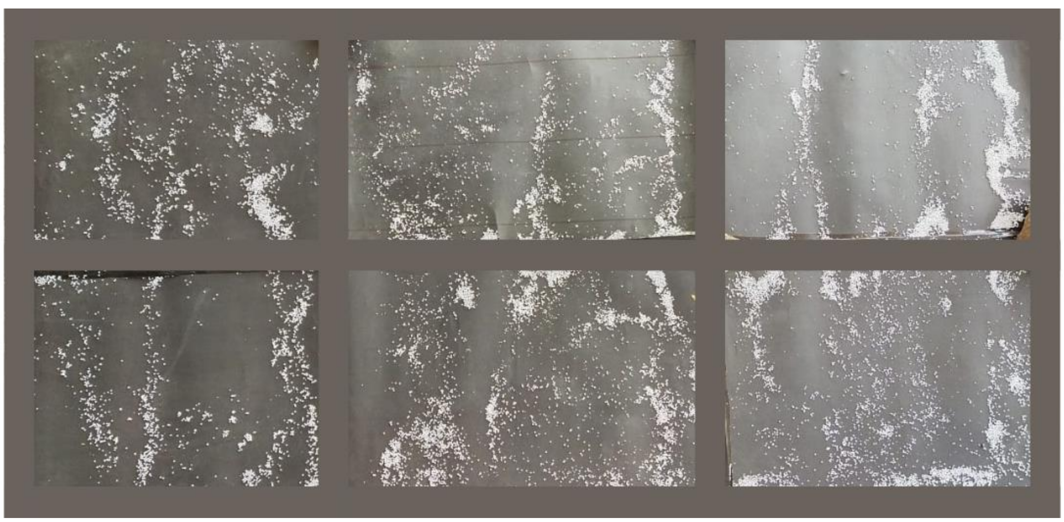


Figure 23: Fertilizer distribution for opening diameter @1.5cm

From the three figures shown above it is clear that as opening diameter increases the flow rate increases which is indicative of our flow rate determined by experimentation. The flow rate of our largest disk hole (Opening Diameter of 2cm) comes out to be **20grams/sec (1200g/min).** Similarly, for 1.75 and 1.5cm it comes out to be **913.8g/min** and **650.1g/min** respectively. The picture with largest opening has most grain application overall and can be clearly distinguished from each other considering their opening diameters.

Note: The mass from grains shown in pictures above does not include the weight of grains that didn't fall on the sheets so the values used in our regression will be lower than the fertilizer mass per 10sec as determined by the flow rate of opening size.

Another thing worthy of consideration is the distribution pattern where granules from larger opening are move evenly distributed. This can be explained by variation in tangential force resulted by granules falling on a more widespread region of the disk instilling more variation curvature angle and radial coordinates.

Our main goal was to develop a disk spreader where the fertilizer flow rate can be actively controlled. We choose opening diameter because it has significant impact on the application rate compared to other control variables. With the results shown in the pictures our goal is essentially accomplished.

Regression Analysis:

Regression Analysis is performed to expand the results of our experiments. From the experiment it is hard to discretize the sample weight distribution and define it as a function of proximity and diameter which is very essential in Analyzing the spread pattern and application rate of our fertilizer. With our main objective taken care of earlier than intended i.e., The fertilizer flow rate control, we wanted to expand the scope of our project. After looking into various literature, we realized, Although difficult to fully encompass various needs of the fertilizer industry with our limited time and resources, we still can shed some light and assimilate useful information using this method.

With our Analysis, we can essentially determine the optimum values above mentioned variables for various crop fertilizer application needs while also evening out the fertilizer spread pattern.

The experiment is performed in hovering flight condition where a particular disk hole is engaged with the hopper for a run time of 10sec. The collection sheet position remains consistent through all the runs and after each run the sheets within a specific proximity range is collected and the samples are weighed.

We also used accumulated sample weight as an actual dependent variable because it effectively couples the proximity & diameter values with sample weight in a discretized manner which is easier to analyze.

Opening Diameter [cm]	Proximity [Ft]	Sample Weight[g]	Accumulated sample weight[g]
2.00	2.7	56.1	56.1
2.00	5.4	79.2	135.3
2.00	8.1	44.6	179.9
1.75	2.7	38.3	38.3
1.75	5.4	62.5	100.8
1.75	8.1	30.7	131.5
1.50	2.7	22.5	22.5
1.50	5.4	45.2	67.7
1.50	8.1	28.4	96.1

Table 2:Base experiment table

The value in second column is actually the proximity range e.g., Considering the first row in the table, the weight of sample is obtained by collecting the sheets within the proximity range of 0 to 2.7 ft.

The Regression Analysis is performed in MiniTab using an objective based regression model [including weighted column and residual minimization algorithm with random test inputs]. The Final Regression Equation is given below.

$$\boldsymbol{w_{accu} = -91.2 + 22.9 * \Phi_d - 5.94 * d_{pr} - 1.902 * d_{pr}^2 + 18.59 * \Phi_d * d_{pr}}$$

Here,

w_{accu} : Accumulated sample weight

Φ_d : Opening Diameter

d_{pr} : Proximity from the Disk spreader.

By using the Regression Equation above we can expand our result field beyond the experimental solution. For example, consider we need to determine the sample weight for the following variables.

1- Opening Diameter of 1.6cm
2- Proximity from the Disk spreader of 2.9 to 3.9

The weight of sample comes out to be **22.8g.** Which means that 22.8g of fertilizer will be distributed along a spread width of 3.5 Ft and proximity range of 2.9 to 3.9Ft whereas the diameter is set to 1.6cm.

The RMSE of equation values is under 5% when comparing with the experimental values. This can be further minimized by using a larger experimental solution field.

Note: The results can be determined with reasonable accuracy from within the sample range only i.e., Going beyond the extremes of Diameter and proximity ranges mentioned in tables will affect the accuracy of regression equation.

By observing values in Table 2, we can see that as the opening diameter decreases the sample weight increases on the far end of the collection sheets. This can be explained by gate location that determines the bead fall coordinated on the disk, curvature of the vane that results in varying rolling friction. As diameters decreases more of the particles end up at far side of vane as they are reflected resulting in them reaching far. The Regression Equation also accounts for this sensitivity variation in the experimental solution.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

As of now we have selected the type of fertilizer spreader which is the centrifugal type in comparison to the pneumatic type. We have successfully developed a control system to not just control flow rate but also RPM of the BLDC motor. The finalized code is shown in Figure 16 & Figure 19.

We have finalized the disc dimensions and the Housing for the spreader and performed experimentation on the prototype which clearly validate our functioning of feed rate control system. Excel calculation is used to optimize the dimension and tweak the required torque value accordingly as it is very important in deciding our Motor Torque Specification (Several product datasheets will be looked up later). There are other factors that have been influenced with disk optimization. With our careful selection of disk design variables, we have obtained an even distribution of fertilizer which can be seen under Feed rate control heading and with no imbalance we were able to run our disk at an RPM of 1500 smoothly.

While our focus was solely on the feed rate control, we did perform some experimentation for fertilizer application per cubic feet in a standard hovering flight condition. The results table has been expanded using regression analysis. The scope of this project can be increased further by performing experimentation considering variable like elevation, RPM, Other disk and vane configurations to perform further optimization for a specific application.

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