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AUTOMATED SEED SOWING MACHINE FOR UNEVEN SURFACE

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Abstract — Seed sowing is a crucial agricultural step as it marks the beginning of the plant's life cycle and establishes the foundation for healthy growth and successful cultivation. Traditional manual seeding process methods struggle with uneven surfaces, leading to inefficient seed distribution and reduced crop yields. The solution is by integrating sensors, actuators, and intelligent control systems to address these challenges. This study proposes an automated seed sowing machine designed specifically for uneven surfaces. The mechanism employs the combination of mechanical design and automation using microcontroller to

and Assembly	assess real-time conditions. A central control unit processes this data to adjust seeding depth, spacing, and rate dynamically. It features a precision seeding unit with electric actuators for accurate seed placement, along with a robust chassis and adaptive systems to navigate rough surfaces. Based on the experiment conducted, it is concluded that the machine is capable to execute the seed sowing task properly.

I. Introduction

Uneven surfaces present substantial obstacles for traditional manual seed sowing methods as they require more labor and effort to be completed. These frequently lead to uneven seed distributions especially towards the end of shifts when workers are fatigued. Consequently, this will lower crop yields.

Innovative and automated approaches that can effectively plant seeds over a variety of surfaces are becoming more and more necessary to address this problem [1][2][3]. In response, this research presents an automated seed-sowing system that can traverse uneven surfaces and effectively plant seeds. Through optimizing crop production and seed placement efficiency, this mechanism intends to revolutionize agricultural practices by fusing the flexibility of hand pushing with the accuracy of automated seed distribution. Through the use of sophisticated motors, automation technologies, and sophisticated control algorithms, this system provides real-time changes for seeding depth, spacing, and rate, guaranteeing excellent distribution despite the roughness of the surface.

Robotics, automation and Internet of Things (IoT) applications have been widely deployed to monitor various industries including agriculture [4][5][6][7]. Automated seed sowing machines have emerged as crucial technological solutions to address the challenges faced by traditional manual methods in agriculture. Kumar et al. [8] aimed to design an automatic seed sowing machine with the main goal was to address the challenges associated with manual seed sowing, such as labor intensity, inconsistent seed distribution, and limited efficiency.

Meanwhile, Balappa et al. [9] developed a semi-automated sowing machine capable of accommodating multiple crop types. The design included mechanisms for seed selection, placement, and adjustment to accommodate various seed sizes and planting configurations. On the other hand, Arteaga et al. [10] developed a tray seeder machine to improve efficiency and precision in seed sowing. They utilized automation technologies to enable features for automated seed loading, distribution, and depth adjustment to ensure uniform planting and optimize seed utilization.

Additionally, Senthil Kumar et al. [11] aimed to design and fabricate a multi-functioned seed sowing machine capable of addressing various agricultural needs. The objective was to develop a versatile solution that could perform multiple functions, such as seed selection, sowing depth adjustment, and row spacing customization. Apart from that, Rajeshwari et al. [12] stressed the necessity of robotics, automation, and IoT in precision agriculture, exemplified by a rover controlled via smartphone through Wi-Fi connectivity. Nagdeve et al. [13] addressed issues regarding labor availability and technical expertise by proposing a proper working procedure for automated seed sowing mechanisms. Gautam et al. [14] highlights the advantages of mechatronics over mechanical system in precision working costs and time for digging and seed sowing planting. All researchers [7]-[12] agreed of the importance to reduce human effort and speed up the sowing process through the development of a machine for automating critical activities.

Despite these advancements, there remains a gap in the literature concerning automated seed-sowing machines tailored for uneven surfaces. This research aims to fill this gap by introducing a novel automated system specifically engineered to address the challenges posed by irregular terrains. Consequently, the objectives of the studies are as follow:

i. To design and develop an automated seed sowing machine for uneven surface
ii. To determine the design requirements for automated seed sowing mechanism
iii. To evaluate the effectiveness of the proposed automated mechanism

II. Research Methodology

This section outlines the study's methodology. It will discuss and elaborate on the techniques, equipment, and software utilized to carry out the study and achieve the objectives. First, the strategy for achieving objective (i) and (ii) is to identify the design requirements for developing an automated seed sowing mechanism for uneven surfaces. Methods for obtaining design requirements and selecting the best design were presented in order to create a prototype that meets the requirements while also being convenient for the end user. The prototype design was chosen after performing a study to determine market demand and user characteristics. The data analysis in the results and discussion is useful for understanding and contextualize the collected parameter in order to derive relevant inferences and implications from the study's findings.

A. Design Requirements

There are three design requirements considered in this research. Design of the seed sowing machine should focus to maximize manufacturing and assembly costs through the application of Design for Manufacturing & Assembly (DFMA) principles. This means standardizing parts and simplifying the design by reducing the number of elements in order to save production costs. By creating parts that are easy to assemble without the need for specialized tools and speed up assembly processes, labor costs can also be decreased.

Additionally, the design should enable portability by complying with the Design for Disassembly (DFD) concepts.

This is due to the reason that the machine will not be left at the site, user may need to transport them by using personal transportation medium. Therefore, there is a need to design a machine that is portable. One of the ways is to have detachable parts. Thus, its modular form allows for easy disassembly and transportation of smaller components. Quick-release mechanisms are incorporated to enhance portability even more by facilitating the rapid disassembly of major components.

Using this method, designers may reduce disassembly time, shorten maintenance hours, and boost overall sustainability efforts. In the realm of user-centered design, placing controls within easy reach and organizing them logically minimizes the need for excessive reaching or stretching, thus facilitating more efficient and less physically demanding operation.

The automated seed sowing mechanism incorporates adjustability and customization, catering to individual user needs and accommodating diverse working conditions, particularly focusing on adaptability in handle and control interfaces to ensure seamless interaction and adaptability in various environments.

Finally, ergonomics considerations are taken into consideration while applying the principles of Design for Ergonomics (DFE). Customizable parts like handlebars and controls are made to fit operators of varying heights to guarantee operator comfort and accessibility.

Design for Manufacturing & Assembly (DFMA) principles are integral throughout the product development process, starting from the initial design concept to material selection. At the concept stage, DFM ensures that proposed products can be efficiently and economically manufactured without compromising quality. User surveys provide valuable insights into user preferences, which influence design choices while briefly considering manufacturability constraints.

During concept screening and scoring, DFM criteria help evaluate concepts based on technical feasibility, cost, and alignment with manufacturing processes. Material selection is guided by DFM principles, emphasizing materials that are readily available, compatible with manufacturing methods, and cost-effective. By integrating DFM throughout the design process, products can meet user needs while being efficiently manufacturable and maintaining high quality.

The consideration of DFD, DFE is critical to improve the mechanism's efficiency, usability, and sustainability. DFD recommends making a product easy to disassemble for maintenance, repair, or recycling. Furthermore, DFE guarantees that the product is comfortable and safe to use by considering elements such as posture and exertion during the assembly and disassembly phases. By adding DFE and DFD, the goal is to develop a product that is not only user-friendly and ergonomic, but also ecologically sustainable throughout its existence, increasing its total value and effect. Rapid Upper Limb Assessment (RULA) method will be used to assess the ergonomic aspect and to evaluate the risk factors associated with musculoskeletal disorders (MSDs) when operating the seed sowing machine. Anthropometric data for Malaysians [14] has been used as the reference when designing the prototype. Additionally, the materials used to develop the prototype include:

- Hollow Steel 1'x1' & 2'x2'
- Steel plate 5'x5'
- Rubber Wheel with bearing and nuts
- 5 bolts & nuts
- Wooden Plank 8'x3/4'
- Rubber Motorcycle Handle Grip

- 3' screw
- Custom Plastic Seed Storage
- Arduino Uno
- Servo Motor
- Buzzer
- Bread Board
- Square Plastic Storage

The material selection process for fabricating a seed sowing machine involves careful consideration of several factors, including price, sustainability, and practicality. Hollow steel is chosen for its affordability and structural strength, making it suitable for essential components while also contributing to sustainability through its recyclability and reduced material usage. Steel plates are selected for their versatility, providing rigidity for various machine parts such as the seed hopper and support brackets, with a focus on balancing cost-effectiveness and sustainability through recycled content. Rubber wheels offer traction and shock absorption at a reasonable cost, with sustainability considerations guiding the choice towards natural or recycled rubber options. Their durability reduces environmental impact by minimizing the need for frequent replacements. Wooden planks, chosen for affordability and ease of customization, are utilized for non-structural elements like handles and control panels, with attention to sustainability achieved through selecting responsibly sourced or recycled wood. This comprehensive approach ensures the seed sowing machine meets functional requirements while remaining economically viable and environmentally friendly throughout its lifecycle.

B. User Survey

Figure 1 shows the highest vote in the user poll suggests a major issue with manual seed-sowing methods, specifically the difficulty in maintaining constant seed spacing between seeds. This study highlights the important challenge users confront in obtaining consistent seed dispersal. In Figure 2, most responses in the user poll emphasize the crucial importance of adjustable seed spacing in an autonomous seed-sowing system. This illustrates the user's need for a methodology that allows for adjustable seed spacing design, so overcoming a significant challenge with manual techniques and ensuring precise and adaptable planting for a wide range of crop and field conditions. The insights gathered from the user survey played a pivotal role in defining and shaping the criteria that were subsequently used for the concept scoring table.

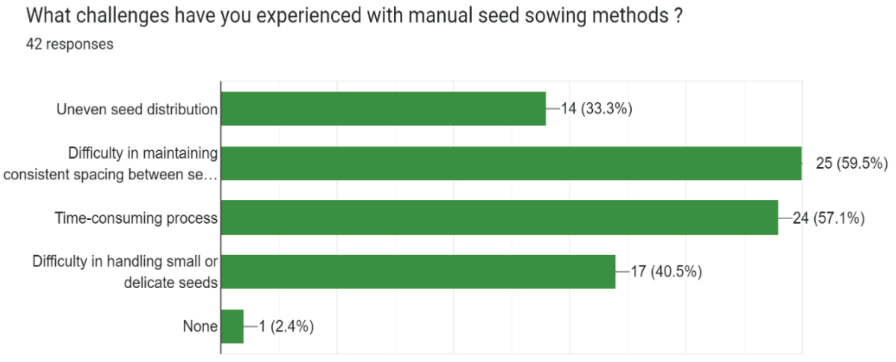

Figure 1: Challenges with manual seed sowing poll

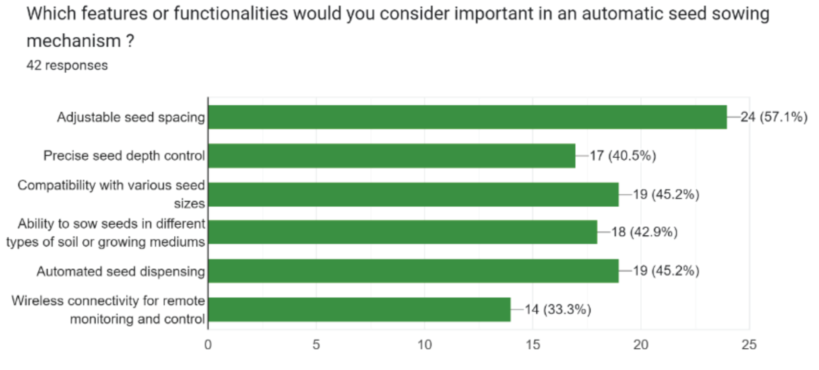

Figure 2: Important features in automated seed sowing mechanism

C. Design Evaluations

Four indexes were used to indicate if the proposed design is appropriate. The indexes are crucial in designing a prototype for a seed sowing machine because they directly relate to the efficiency and effectiveness of the machine in planting seeds.

Multiples Index (MI):

The Multiples Index assesses the uniformity of plant spacing by considering the distances between plants and their multiples. The formula for the Multiples Index is given by:

$$MI = \sqrt{\frac{\sum_{i=1}^{n}(D_i - \bar{D})^2}{n}} \quad (1)$$

where:

- n is the total number of plants
- Di is the distance of the i-th plant from its nearest neighbor
- $\bar{D}$ is the mean distance between neighboring plants

Miss Index (MI):

The Miss Index assesses the average deviation of individual plant spacings from the target or desired spacing. The formula for Miss Index is given by:

$$MI = \frac{\sum_{i=1}^{n}|D_i - D_{target}|}{n} \quad (2)$$

where:

- n is the total number of plants
- Di is the distance of the i-th plant from its nearest neighbor
- D_{target} is the target or desired plant spacing

Feed Quality Index (FQI):

The Feed Quality Index assesses the quality of plant distribution for efficient resource utilization. The formula for the Feed Quality Index is given by:

$$FQI = \frac{1}{n}\sum_{i=1}^{n}\left(1 - \frac{|D_i - \bar{D}|}{D_{target}}\right) \times 100 \quad (3)$$

where:

- n is the total number of plants
- Di is the distance of the i-th plant from its nearest neighbor
- $\bar{D}$ is the mean distance between neighboring plants
- D_{target} is the target or desired plant spacing

Precision Index (PI):

The Precision Index assesses the precision or consistency of plant spacing, considering both the average spacing and the variation around that average. The formula for the Precision Index is given by:

$$PI = \frac{\bar{D}}{s} \quad (4)$$

where:
- $\bar{D}$ is the mean distance between neighboring plants
- s is the standard deviation of plant spacing

D. Experiment Setup

The experiment was conducted in a private agriculture land in Sendayan, Negeri Sembilan. The size of the area is approximately 30 meters square. Cabbage seed was used in the experiment within a land area of flat terrain with uneven surface.

III. Results and Analysis

The user survey data directly influenced the establishment of design requirements, ensuring that the final product aligns closely with user preferences and needs.

To achieve portability and facilitate installation and disassembly, a prototype of the automated seed sowing mechanism was constructed utilizing a bolt and nut assembly method, employing the design concept of detachable and adjustable profile. In order to satisfy DFD, Boothroyd Dewhurst method as shown in Table 1 was utilized. The method determines part complexity and the corresponding assembly/ disassembly times. When analyzing DFD data, the table helps identify difficult-to-disassemble components, allowing designers to prioritize simplicity. The table shows the proposed assembly time for the mechanical components of the machine, which means 5.75 minutes is needed for assembly/ disassembly procedure to be done if the machine needs to be fully disassembled before it can be loaded for transportation purpose.

Additionally, easiness to controls and interfaces are important in Design for Ergonomics (DFE) principles. This contributes to an ergonomic interface that enhances user experience and operational efficiency.

Table 1: Details on assembly/ disassembly times for the automated seed sowing machine based on Boothroyd Dewhurst method

No.	Part Name	Quantity	Min Part, Nm	Total Handling Time (s)	Insertion Time (s)	Operation Time (s)	Operation Cost (cents)
1.	Body Frame	4	1	60	0	60	0.25
2.	Wheels	2	1	5	120	125	0.52
3.	Handle	1	1	5	60	65	0.27
4.	Ridger	1	1	5	5	10	0.04
5.	Tiller	3	1	5	10	15	0.25
6.	Seed Sowing Mechanism	4	1	60	120	180	0.75
	Total	15	-	30	315	345	2.08

Figures 3 and 4 illustrate the concept design and the developed prototype respectively. Additionally, Figure 5 depicted the microcontroller circuit design using Tinkercad software.

Figure 3: Design concept

Figure 4: Developed prototype

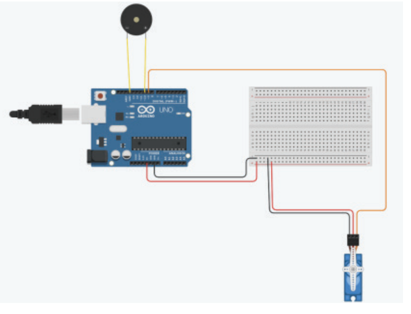

Figure 5: Microcontroller circuit design

IV. Discussion

The seed sowing mechanism was tested using a Randomised Complete Block Design (RCBD) and three replications, accounting for field slope interference. The experiment assessed three planting speeds (0.6 m/s, 0.8 m/s, and 1 m/s); and two planting depths (1.5 cm and 2.5 cm), with a theoretical plant spacing of 25cm. the data underwent ANOVA analysis via SAS software. Mean differences were determined using the Duncan Multiple Range Test (DMRT) to ascertain the significance of factors.

The choice of the best parameter for the seed sowing process depends on specific priorities. The precision in managing seed quantity and dispersion is the primary concern as shown in Table 2.

Table 2: Effect of Planting speed, Seed quantity and Planting depth

INDEX				
Treatment	Multiple	Miss	Feed	Precision
Planting Speed, **S** (m/s)				
0.6	0.2311	0.0364	0.9587	0.1365
0.8	0.0578	0.0233	0.9897	0.1326
1.0	0.2665	0.0017	0.9523	0.1253
Planting Depth, **D** (cm)				
1.5	0.00322	0.0195	0.999	0.2668
2.5	0.003222	0.0186	0.999	0.2674

Based on the result, Treatment 0.8 generally has lower values for "Multiple" and "Miss" compared to the other treatments, which is desirable. Treatment 1 generally has higher values for "Feed" and "Precision" compared to the other treatments, which is also desirable. Considering these factors, Treatment 0.8 appears to perform the best overall, as it achieves relatively lower values for "Multiple" and "Miss" while also achieving higher values for "Feed" and "Precision". Therefore, based on the analysis conducted, Treatment 0.8 is likely the best choice among the options provided (0.6, 0.8, and 1) for achieving the desired outcomes.

Meanwhile, for Planting Depth where lower values are desired for "Multiple" and "Miss" while higher values are desired for "Feed" and "Precision" the result shows that both treatments have very low values for "Multiple" and "Miss," which is desirable. Both treatments have the same value of 0.999 for "Feed," which is the desired value. Treatment 2.5 has a slightly higher value for "Precision" compared to Treatment 1.5, which is also desirable.

Considering these observations, both treatments seem to perform well based on the desired outcomes. However, Treatment 2.5 has a slightly higher value for "Precision," which may indicate slightly better performance in terms of precision. Therefore, based on the analysis conducted, Treatment 2.5 may be slightly preferred over Treatment 1.5. However, the differences between the two treatments are relatively small, so the choice between them may depend on other factors such as cost, feasibility, etc.

Figures 6 and 7 illustrate the results that have been discussed. (Note that the average for Multiple & Miss Index are proportional to Feed & Precision Index). With regards to both figures, the notation for indexes is as follows:

1: Multiple Index
2: Miss Index
3: Feed Index
4: Precision Index

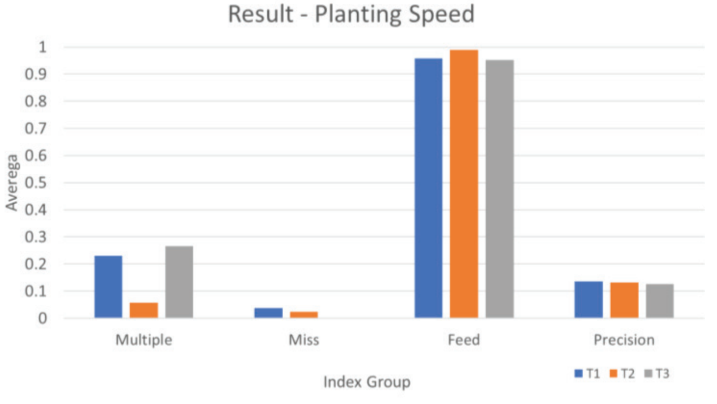

Figure 6: Planting Speed

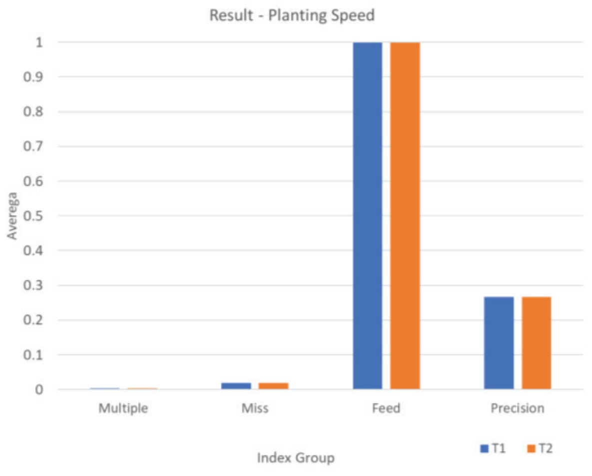

Figure 7: Planting Depth

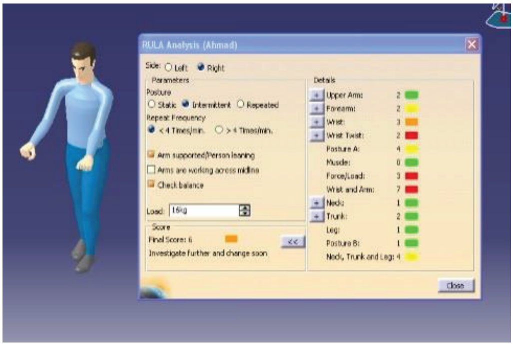

Figure 8: RULA analysis

The RULA investigation reveals several major ergonomic considerations related to tasks. While there is a relatively minimal danger connected with the posture of the upper arm and neck, there are significant worries about other vital regions of the body. While the forearm position is deemed somewhat harmful, the wrist posture and degree of wrist twisting are categorized as high risk.

Moreover, the combined posture of the wrist and arm as well as the force/load exertion carry a very significant risk. These findings indicate that poor posture and excessive force application during task performance are associated with a higher risk of musculoskeletal disorders. The overall RULA score of 6 for the orange zone emphasizes the need to provide solutions, especially in prolonged working conditions. This is illustrated in Figure 8.

V. Discussion

The research successfully achieved its goal of designing and developing a prototype with genuine countermeasures. Throughout the design phase, prior studies, benchmarking, and the implementation of DFMA guided the development process. The design criteria for the automated seed-sowing mechanism on uneven surfaces reflected a deep understanding of the project's challenges and objectives. The resulting design emphasized flexibility, precision, and efficiency in addressing the complex topography of uneven surfaces, thereby meeting the project's goals effectively.

VI. Acknowledgement

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