DESIGN OF AN AUTONOMOUS WEED REMOVAL SYSTEM

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ABSTRACT

A systematic design of an autonomous weed removal system developed in the virtual CAD environment is described in this paper. The objective of the proposed design is to cut weeds of size greater than 3 feet mechanically and collect the same with it. The system can function autonomously in a few selected agricultural fields. The long-term intent of the project is to overcome the challenges faced by the existing solutions for weed removal and also to promote automation in the agricultural sector in an economically feasible manner for the farmers of India.

This paper describes the design approach and the mechanical aspects of the proposed system. A static analysis of design followed by product sustainability analysis using CML environmental impact assessment methodology is also discussed in detail.

CCS CONCEPTS

• Applied Computing ⟶ Computer-aided design

• Computing methodologies ⟶ Model Development and Analysis

KEYWORDS

Autonomous Weeding robot, Agricultural Machine, Mechanical Design

1 INTRODUCTION

Availability of unskilled labor, willing to work in the agricultural industry is decreasing day-by-day. Nevertheless, the demand for laborers in agriculture remains, as it was earlier. As a result, farmers have to pay more for laborers. However, there are systems or machines been developed in India which perform a few of the agricultural tasks (harvester, thresher, etc.), but many activities still require human interaction or are not automated. Weed (wild plants found in the agricultural field) cutting or removal is one of the tasks done by laborers by hand pulling, by weed removal tool or by machines operated by the laborer.

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As per the statistical data released by ICAR, India loses agricultural produce worth over $11 billion annually to weeds (more than the Centre's budgetary allocation for agriculture for 2017-18) [1]. Weeds account for about one-third of the total losses caused by agricultural pests [2]. As per the DWR 2015 report "The farmers are in direct need of cost-effective weed management technologies for increasing productivity and profitability. Non-availability of labor for weed control is an emerging issue." [2].

Hence, a novel design of an Autonomous weed removal system is provided as a solution to the problem statement addressed.

2 DESIGN APPROACH

2.1 Overview:

The design approach followed for the previously described problem is illustrated in the following Flowchart, Figure 1. The process initiates from the market survey and goes up to the generation of detailed manufacturing manual with its BOM, Product Sustainability report using CML environmental impact assessment methodology and product costing report in INR. Further, prototyping and field test of the design is considered as future scope of the project.

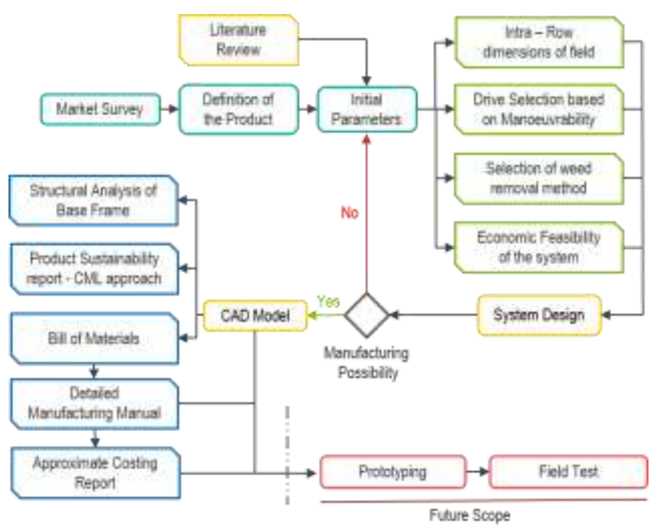

Figure 1: Design Flowchart

The design was developed completely in a virtual CAD environment. The CAD model was made in Solidworks software and its structural analysis was executed in ANSYS software. Further, the design's Sustainability calculations, cost estimation and motion study of inverted Stewart platform sub-assembly were carried in Solidworks software.

As part of the system design, a method of top-down approach was followed to design the parametric CAD model. Initializing with the assembly layout formation consisting global variables and dimensions chosen according to the initial parameter considerations (as discussed in section 2.3) followed by parts generation and its grouping in various flexible and rigid sub-assemblies, the parts generated were subsequently re-created using bottom-up approach to remove all external references and parent to child relationships of dimensions used in the initial CAD model (of top-down approach). This resulted in a diverse and structured design tree-house (A representation of the hierarchical distribution of Top assembly and its different sub-assemblies and parts). The design includes the use of various advanced weldment and Sheetmetal features following the standard DFM guidelines to make its manufacturing unexacting, geographically viable and economically feasible.

2.2 Existing Work:

Numerous weed removal robots have been made either as a product (for example, "Bonirob" by Bosch [12]) or as a prototype [3] with each having a distinguishing feature. The designs were studied and the disadvantages faced by them were taken for consideration in the proposed design. Review article – "Agricultural robots for field operations: Concepts and components" [6], [7] highlights a few weed control robots. It was observed that existing designs doesn't collect weed after cutting [3], [8]. Leaving behind the cut weeds on the field may lead to re-growth of weeds [2], [4]. Hence, the collection of weeds was taken into consideration as one of the objectives of the resulting design.

2.3 Initial Parameters Considerations:

The gap between two crop rows of an agricultural field, which is ideally considered to be of 30 inches [5] was considered as the maximum width dimension of the system. Keeping in mind the objective of the design, method of mechanical cutting of weed was finalized for the system based on review [9]. As an economical advantage over other methods of weed removal as listed in [15], the method of mechanical cutting has not the obligatory requirement of weed detection, hence is disregarded for the design. Economic feasibility and manufacturability of the system were also considered as a design parameter. Considering the agriculture field terrain and system's maneuverability in inter-row trajectories, a caterpillar / Track drive system was finalized.

3 SYSTEM DESIGN

Systematic design of an Autonomous Weed removal system with an objective of cutting weeds of size greater than 3 feet and collection of the same with it is described in this section.

The design further aims to eliminate the need for unskilled labor for the task of weed removal by performing the task autonomously. Further, the farmer can control the system remotely, by manual override. As per the costing report, the system's manufacturing cost is estimated to be RS. 2.67 Lakhs. In order to make it affordable for small farmers in India, the system can be purchased in a group or can be made available on rent to the farmer.

Variables	Dimensions	Advantages
Length	1110mm	Easy turns & rotations
Width	660mm	Width less than the average distance between 2 crop rows
Height	630mm	Low CG /Fewer chances of getting toppled

Table 1 - System Dimensions

Figure 2 previews the vehicle's envelope, while the outer dimensions and its advantages are highlighted in Table 1.

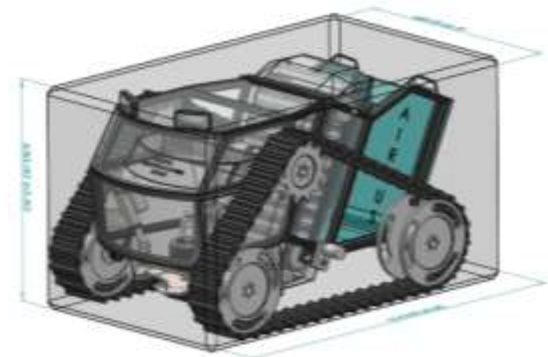

Figure 2: System Envelope

The system design is divided into various sub-assemblies as denoted in Figure 3. Each sub-assembly is described in detail in the subsequent sections.

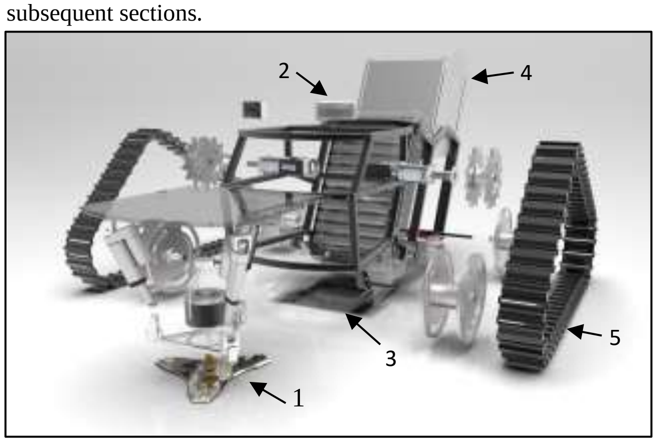

Figure 3: System Exploded View

(1-Inverted Stewart Platform, 2-Chassis, 3- Conveyor, 4-Collector module, 5-Drive)

3.1 Inverted Stewart Platform Sub-Assembly:

The sub-assembly is mounted on the lower front end of the chassis. It consists of 3 linear actuators, with one end of each linear actuator mounted to a platform and the actuating end of each, attached to a frame through universal joints. All three linear actuators are at 120 degrees horizontally to each other, and at 30-degrees with respect to vertical, in its default position. The structure results in an inverted Stewart platform. The frame holds a BLDC motor coupled with a standard weed cutting blade. An orientation sensor (BNO) [10] is placed above the BLDC motor, enclosed in a box (to protect it from the environment and the magnetic field created by the motor).

Figure 4: Inverted Stewart Platform Sub-Assembly

The inverted Stewart platform helps in maintaining the orientation of weed cutting blade with respect to ground. A parallel orientation is to be maintained by the blade in general, regardless of the current orientation of the overall system. The sensor provides feedback on the current orientation of the motor frame to the processor. Upon change from the desired orientation, the linear actuators are triggered accordingly, to bring it back to the desired orientation. Figure 4 provides a rendered image of the sub-assembly, while the block diagram in Figure 5 highlights the workflow of the sub-assembly. Apart from maintaining a parallel orientation in general case, the sub-assembly is capable enough to orient the blade in other desired positions. Hence it results in a bigger work envelope for weed cutting blade. The cutting blade cut weeds and the weeds get thrown away tangentially. Hence the blade is to be selected accordingly so that the weeds get thrown backward and get collected by the scoop further.

3.2 Base Frame (Chassis) Sub-Assembly:

It is a Welded Base frame consisting of standard ISO Square channel of 20x20x2mm on which other sub-assemblies are mounted. It provides structure to the overall system. The acrylic sheet enclosure ensures the blade and electronics sub-assembly are protected from the external environment. Further, it doesn't allow the cut weeds to get thrown away from the system and allow them to get collected by the large scoop.

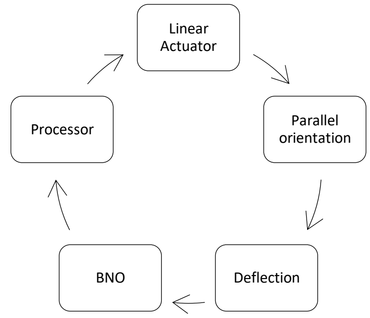

Figure 5: Inverted Stewart Platform Workflow

3.3 Conveyor Sub-Assembly:

It consists of a vertically inclined conveyor wrapped by a Sheetmetal enclosure. The enclosure further extended up to weed cutting blade, acting as a scoop to collect the cut weeds. The cut weeds may either fall directly on the scoop or on the field. The ground clearance of the scoop is maintained very low so that as the system moves forward, the cut weed on the ground get collected in the scoop. Further, the holes provided in the large scoop act as a filter to remove unwanted clay and other minute particles coming on its path. A load cell (round force sensitive resistor) [11], is placed below the scoop, which senses the current weight of the scoop and sends the data to the processor. As weeds get collected on the scoop, the weight increases. As it reaches a pre-defined value (~500g), the conveyor is triggered.

The conveyor consists of two double-sided timer belts, engaged with two driven and driving spur gears (pulley). The shaft is coupled to a geared DC motor (required torque – 6.795 kg cm) mounted on chassis. The two belts are connected using a connecting rod. A small Sheetmetal scoop is welded on this rod. As the belt moves, multiple instances of small scoops attached to their respective rods moves with it, carrying the weeds collected below in large scoop. The collected weeds from small scoops are dumped into Collector module. Figure 6 illustrates the timer belt engaged with the spur gear and small scoops.

Figure 6: Conveyor Sub-Assembly

Parameter	Value
Volume of primary scoop	9780 cubic.cm
Volume of secondary scoop	754 cubic.cm
Number of secondary scoops	26
Volume of detachable module	66580 cubic.cm
The weight of weed required in the primary scoop to trigger conveyor Subassembly (Approximately)	500g
weight of weed carried by the secondary scoop	38.5 g

Table 2 - Design Parameters

Once the Collector module is about to fill completely, the system goes to the nearest docking point and communicates to the farmer to empty the module. Table 2 outlines the measured values of parameters related to conveyor Sub-Assembly. Figure 7 elucidates the inner conveyor system with the translucent exterior enclosure.

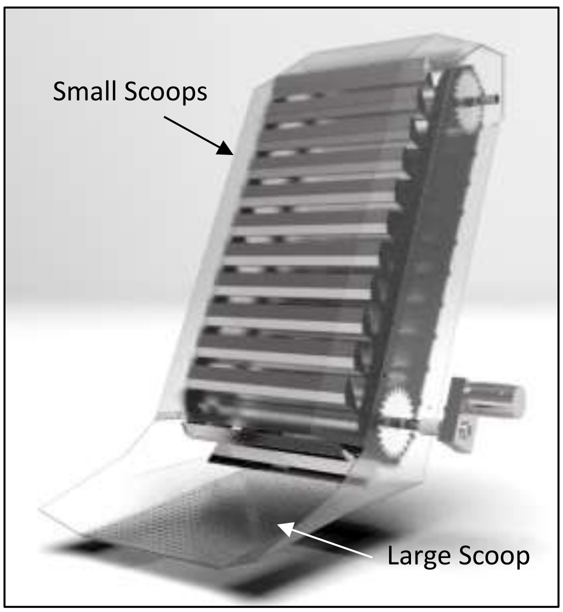

Figure 7: Conveyor Sub-Assembly with Enclosure

3.4 Detachable Collector Module:

The sub-assembly is an onboard weed collecting chamber made of Sheetmetal placed at the rear end of the chassis. The module is can be easily removed and placed manually. The weight of weed collected for the volume of 1000 cubic.cm was physically measured to be 0.0510 Kg. Hence, the weight of weed to be collected by the detachable module was estimated to be 3.4 kg for the volume of 66580 cubic.cm. The number of secondary scoops required to fill the module completely is 88, (calculated as - weight of weed carried by collector module (g) ÷ weight of weed carried by secondary scoop (g) = 3403/38.5 = 88.4 ≈ 88).

The number of conveyer cycles required to fill the module is 3.4, (calculated as – No. of cycles required to fill module ÷ no. of secondary scoops = 88.4/26 = 3.4 cycles).

Sheetmetal specifications are as per Gauge 5 of standard gauge table for steel. (Thickness-1mm, k-factor-0.5). Figure 8 shows the collector module sub-assembly.

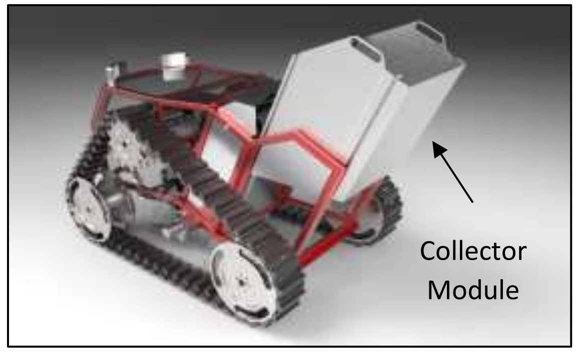

Figure 8: Detachable Collector Module Sub-Assembly

3.5 Drive Sub-Assembly:

A caterpillar/track drive is employed for the task. Each Drive belt is engaged with two driven wheels and a driving wheel. The driving wheel is coupled with a drive motor (Required torque – 165.5 kg cm) mounted on chassis, while the driven wheels are connected to drive shafts. Both the driving wheels are powered independently by separate drive motors coupled with incremental type optical rotary encoders (which provides feedback and helps in locomotion). Hence, a differential motion can be carried easily, which further increases the trajectory capabilities of the system.

4 ANALYSIS

4.1 Static Analysis of Base Frame (Chassis):

Several Finite Element Analysis (FEA) were performed on the chassis design. An approach of different material selection & analysis was followed, with a conclusion based on a comparison of the results.

The maximum overtime deformation of 0.29mm as shown in Figure 9 was noted for the material - Galvanized Cast Iron due to its self-weight.

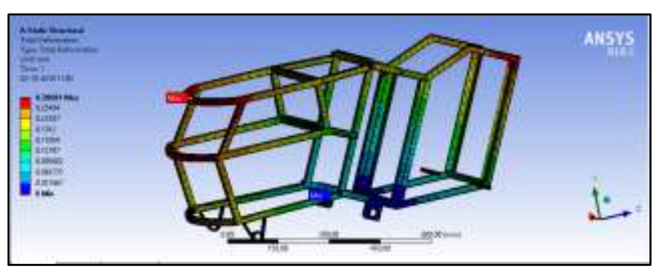

Figure 9: Material – Galvanized Cast Iron

Further, for materials - Structural steel and Aluminum 6061 Alloy, the deformations were similar, ~ 0.17mm, as shown in Figure 10.

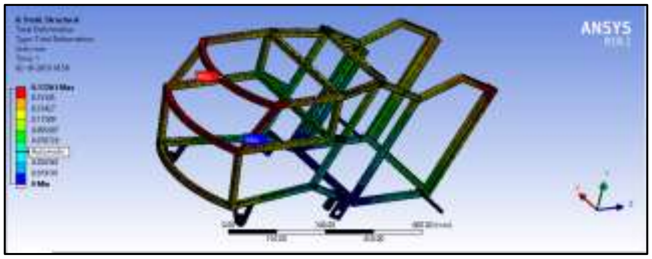

Figure 10: Material – Structural steel

Material selection for other sub-assemblies was done based on standards followed in the market, subsequently, their weights were calculated. An overtime deformation plot due to the weight of other Sub-Assemblies is derived as shown in Figure 11.

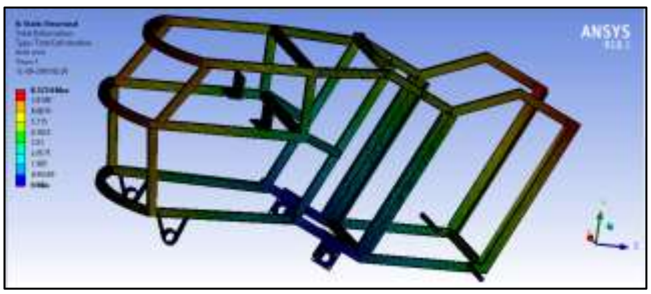

Figure 11: An overtime deformation plot due to the weight of other Sub-Assemblies.

Hence, Structural steel and Aluminum 6061 Alloy were considered for product sustainability analysis, in order to finalize the material for chassis.

4.2 Sustainability report of Base Frame (Chassis):

A comparative sustainability report of the base frame (Chassis) for material Structural steel and Aluminum 6061 Alloy was generated using Solidworks Sustainability toolbox. CML environmental impact assessment methodology [13] was followed to calculate the individual results (for both the materials) and were further compared. As shown in the Figure 12, Structural Steel (Current – Green) had lesser impact on environment compared to Aluminum 6061 Alloy (Baseline – Black) with 63Kg CO2e Carbon Footprint (9% less), 760MJ energy consumption (7% lesser), 0.364 Kg SO2e Air Acidification (6% lesser) and 0.030 Kg PO4e Water Eutrophication (42% lesser) collectively during four different stages of product lifecycle (i.e. Material Extraction, Manufacturing, Transportation and End of Life). The input parameters were assigned as per Sustainability calculation Guidebook. [14]

Product Lifecycle Stages –

Material Extraction
Manufacturing
Transportation
End of Life

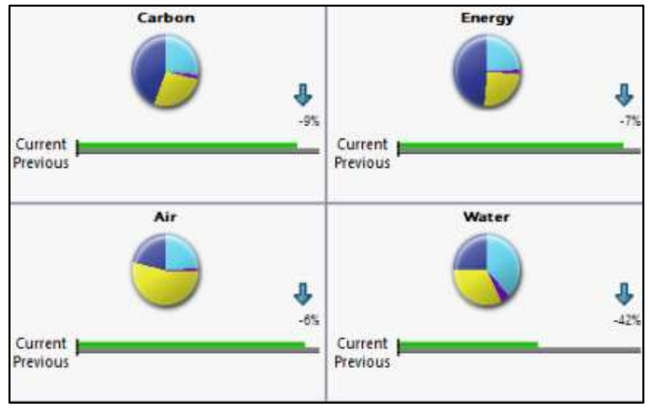

Figure 12: Product Sustainability Report for Chassis (Current – Structural Steel, Previous/Baseline – Aluminum 6061 Alloy)

5 DESCRIPTION TASK

The system is capable to be deployed in the following arena:

1. Orchards
2. Forest plains – to cut forest weeds
3. Grasslands
4. Other agricultural land where weed growth is greater than 3 feet.
5. Roadsides

Upon further iteration and development in the design, autonomous locomotion in all above-mentioned arena is aimed to be achieved in the future scope.

Table 3 highlights the major drawbacks of existing solutions compared to the potential advantages of the design proposed in this paper. Figure 13 illustrates a rendered image of the CAD model.

Figure 13: A Rendered image of CAD Model

No.	Existing Solutions	Drawbacks of Existing solutions	Advantages of the design (overcoming drawbacks of existing solutions)
1	Hand Plucking	• Requires unskilled laborers to execute the task. • Plucking weeds manually or cutting them by a tool in the agricultural field is highly time-consuming. • The farmer pays laborers by no. of hours, hence has to pay more. [2]	• Works autonomously. • No need for constant supervision. • Surveillance or manual override can be done by farmer remotely. • Higher Initial cost, but cheaper method when compared for long term goal. • Cut weeds are collected in an onboard module which is emptied at docking points manually by the farmer.
2	Weed removal by hand tool (Manual Weeder)		
3	Weed removal Machine	• Human operated. • Requires constant supervision. • Cut weeds aren't collected. They are left in the field itself. [2]	
4	Using Herbicides	• Uses toxic chemicals to destroy weeds but affects the health of desired crops also. • Requires a laborer to execute the job. Herbicides may affect the health of laborer also.	• Doesn't affect the health of desired crops/vegetation. • Doesn't affect the health of laborer or farmer.
5	Weed removal Robot	• Designed to work in the specific type of farm having a crop of a specific size. • systems are quite large which does not allow it to be used in different farms having different size of crops and variable distance between rows of crops. • Low modularity (due to size and complex design). • Cut weeds aren't collected. They are left in the field itself. • The systems are very expensive.	• Modular (small in dimensions comparatively) enough with better maneuverability that it can be used in different types of farms easily. • Cut weeds are collected in an onboard module which is emptied at docking points manually by the farmer. • Comparatively cheaper.

Table 3 - Benefits of the system design overcoming drawbacks of existing solutions

6 CONCLUSION

Hence, the design of a low-cost autonomous weeding robot was successfully developed in the virtual environment. It contributes in the direction of automation in agricultural sector overcoming the challenges faced by the existing solutions. Further, apart from the agricultural field (Orchards), the design is mechanically capable to be deployed under human supervision and control in grasslands and forest of plain terrain for plant removal (mechanical cutting). Upon further development and optimization of the existing design (with an additional configuration in the system which cuts or uproots weeds of length less than 3 feet as well) as a future scope, the design with a widened objective may result in an economically feasible and sustainable alternative to farmers.

ACKNOWLEDGMENTS

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