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Design and Simulation of a Robot-Farmer for Gripping and Cutting Crops

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ABSTRACT
Now-a-days every field is heading towards automation, whereas agricultural field is still an exception. Current scenario says many countries do not have enough farmer to cultivate lands and even in Bangladesh there are lots of families that are lacking an able member to toil during harvesting period. To overcome this problem, a robot farmer is the optimum solution. The objective of this research is to design a robot farmer which can work in the crop-fields for automatically cutting and placing crops aside with a pre-installed embedded system. It will reduce the necessity of man-operated machineries. The total design of this robot farmer consists of 7 motors, a distance measuring sensor, and an Arduino board. This research work will be helpful for the researchers who are interested to introduce automation in the agricultural sector and who want to perform any smooth cutting operation which requires holding of an object before cutting.

Keywords: Robot farmer, Distance measurement sensor, Robotic manipulator, Gear based gripping mechanism.

1. Introduction

Modern machineries of the crop field are used mostly for cutting a huge range of crops and those machineries are very expensive which costs around BDT 2 lakh per machine except its operating and maintenance cost. In recent time, few machines are available for rent in some areas of tamilnadu, India by 2000 rupees per hour which is somehow fulfilling few farmers' need. Moreover due to uncertainty of rain and unavailability of laborer, the harvesting remains challenging for rural farmers who cannot afford the money. In fact, in many parts of the world those costly machineries are not even available. To minimize these problems our proposed robot farmer will fulfill the need of the farmers with its structural durability and ease of operation. As a result of these consequences farmer robot can start a new era of farming for individual land owners by helping them to cut their crops quickly and without the physical involvement of human being.

2. Background Research

Fig.1.1 Currently available man operated small machines

Fig.1.2 Currently available costly Crop cutting vehicle

The concept of this farmer robot came from the worldwide implementation of robotic manipulator in industrial fields. So far, only a few studies of introducing autonomous agricultural field machinery have been published. Goense (2003) [1] compared autonomous equipment with conventional equipments and showed that even if the autonomous equipment is utilized 23 hours a day, it would be economically feasible. Later in 2005 S.M. Pedersen [2] showed three scenarios with field scouting in cereals; robotic weeding in sugar beet, and autonomous grass cutting in golf courses. For first two cases he used an autonomous research platform (API). The third analysis was based on real data from the operational costs for grass cutting on golf courses. He therefore have estimated the cost of building an autonomous grass cutting vehicle to replace the existing human-driven vehicles and proved a robotic wedding machine can give 12.2% economic benefit than a man operated grass cutter. But the study resulted in a very costly machine (20834 euro) which is equivalent to 21 lakhs in BDT.

At present, few small man operated cutting machines are available (fig.1.1) in south Asia which are being used but the necessity of carrying the machine makes it tough for a person and the cut crops are also not kept in sequence. For these reasons a huge amount of paddy is wasted. Besides, the machine is run with diesel engine which is not so positive towards the environment and cost. Due to these reasons a better solution in the crop field has become mandatory.

All these things forced our research work to introduce an autonomous crop cutting machine specially for paddy harvesting. In this research, we are showing the model of such an autonomous machine which can be manufactured by locally available materials. This research work actually comprises the basics of a robotic manipulator, an obstacle detector car that detects obstacle with distance measuring sensor, and a rotating cutter. Later in this research, through simulation analysis we have proved its sustainability by using simulation platform solid works which has now got popularity in simulation analysis field. In 2013, V. Kaundal used this platform for his research work [3]. In

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our research work, the electrical circuit and the program algorithm of the robot farmer is provided and eventually the cost is estimated and a comparison is provided between our farmer robot and the currently available man operated machineries of the crop field.

3. Methodology and Design

The robot farmer, designed in this research work consists of three major parts involving a 4 wheeled car, a cutter and a robotic manipulator with 2 degree of freedom. The mechanism involves a distance measuring sensor which is mounted at the front side of the car body (fig 3) to identify the exact location of the nearest crop. After that, two motors drive two rear wheels and lead the robot to take its position near the crop. Then, end effector of the manipulator grabs the crop using a servo controlled gripping mechanism (fig.6 and fig.7) and the cutter comes out of a gear box using rack and pinion mechanism to cut the crop at 6 cm above the ground. Finally, the manipulator arm puts the cut crop aside by the help of 2 revolute joints situated at the bottom and at the wrist. 2 revolute joints of the manipulator are controlled with 2 servo motors.

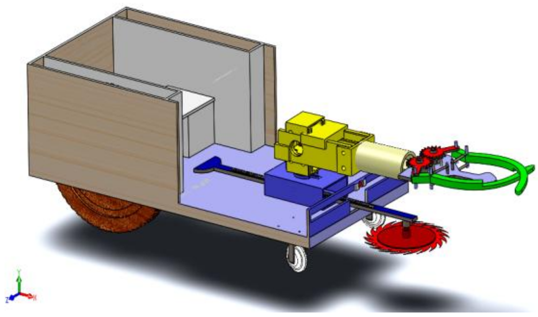

Fig.2 Structure of our proposed robot farmer

4. Mechanical Structure

Mechanical structure of the model of our robot farmer can be divided into 3 individual parts. Each of these parts is subdivided into few more parts. Here is a brief description of the mechanical structure part by part.

4.1 Part 1: Car

Car has three parts. Rear wheels, front wheels and chassis.

(1) Chassis

Aluminum 2014 t-6 sheet metal is used to build the car chassis in virtual environment. The base has a thickness of 10 mm. For upper portions 5 mm thick sheet is used as it is mentioned in figure 3. The model is designed involving the rear wheels inside boxes to ensure the minimum required place for moving of the robot inside a paddy field. It is found by field investigation in the paddy fields of manikgonj and khulna of Bangladesh that, the paddy are planted with 5-6 inch gap between each row. So the chesis is designed with 12 inch width and 10 inch height and 24 inch length so that it can easily move into the field without hampering the crops. As the arm is screw fastened over this chesis, the chessis has to endure axial stress. So, for the reason of stability, Aluminium 2014-6 is used. It's cost is also relatively low (table 3) and it has resonable mechanical properties (table 1).

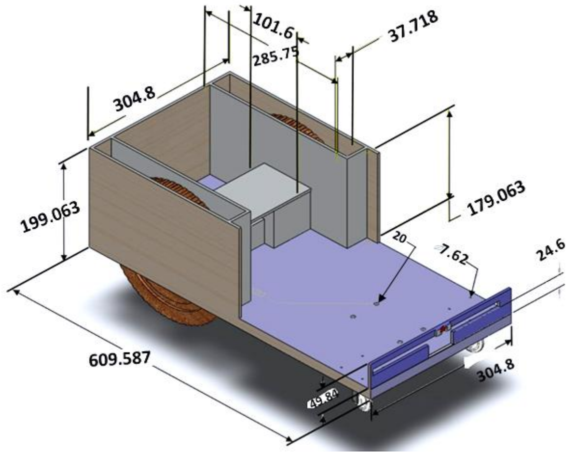

Fig.3 Car chesis of the robot (dimensions in mm)

Table 1 Mechanical properties of Aluminum 2014 t-6.

Properties	Unit(SI)	Scale
Brinwell Hardness	135	AA; load 500 g; 10 mm ball
UTS	483 MPa	AA; Typical
Modulus of Elasticity	72.4 GPa	In Tension
Compressive Modulus	73.8 GPa	
Ultimate Bearing Strength	889 MPa	Edge distance/pin dia = 2.0
Bearing Yield Strength	662 MPa	Edge distance/pin dia = 2.0
Fatigue Strength	124 MPa	AA; 500,000,000 cycles; reversed stress
Machinability	70 %	0-100 Scale of Aluminum Alloys
Shear Strength	290 MPa	AA; Typical

(2) Rear wheels

The rear wheels are chosen to be wooden and highly available mehogany wood is chosen for rear wheel material. Mehogony wood is chosen due to its eco friendly attitude and durability against corrosion and availability in rural areas. These rear wheels are replacable and negociable with any type of metal that posses the similar properties. It is designed with 10 inch diameter and 1 inch thickness.

(3) Front wheels
Front wheels need to rotate freely for movement of the robot. So, these parts are designed with 2 inch diameter moving plastic wheels.

4.2 Part 2: Cutter
Aluminium 2014-6 is assigned to it to ensure necessary strength to the cutter (table 1). Cutter consists of a cutting blade, a blade holder datum and a gear box.

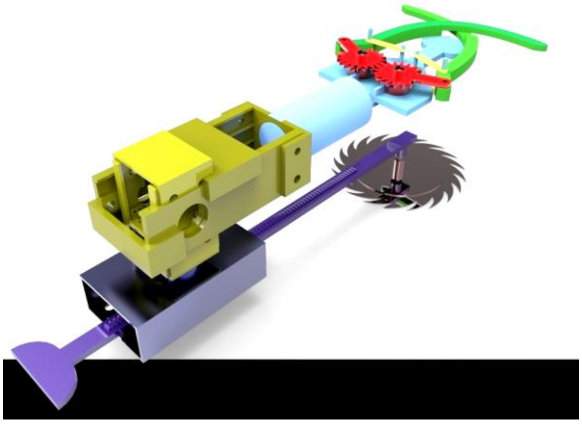

Fig.4 Robotic arm and cutter

(1) Cutting blade
It’s a 6 inch diameter, circular blade. This type of blade is currently used in hand operated paddy cutter machines in India. In the cutting operation, a DC motor will guide this part with a rotation of 1500 rpm for smooth cutting action.

(a) Cutter (idle time)   (b) Cutter (coming out)

Fig.5 Cutter positions

(2) Blade holder datum
Blade holder datum contains the rack type portion of rack and pinion mechanism. There is a pinion gear mounted inside the box (fig 7) guided with a DC motor. It helps the cutter to go forward linearly during cutting operation and helps to come back after the operation.

(3) Gear box
A rack and pinion comprises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move, thereby translating the rotational motion of the pinion into the linear motion of the rack. The gear box of our farmer robot contains a pinion gear and the rack mentioned earlier. The pinion is driven with a servo motor. The gear ratio[4] of rack and pinion will be 1:1

4.3 Part 3: Robotic Arm
This part consists of 4 sub-parts-

- Arm base with bearings (fig.8)
- Arm elbow (fig.9)
- Arm wrist with piping (fig.6,7,10)
- End effector or gripper

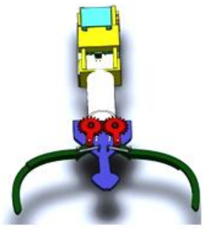

Fig.6 Arm (grip opened)

Fig.7 Arm (grip closed)

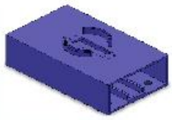

Fig 8 Arm base with bearings (gear box)

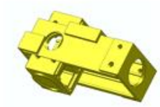

Fig 9 Arm (elbow)

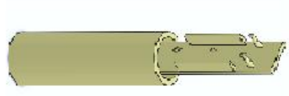

Fig.10 Arm (wrist)

5. Gripping mechanism with end effector
Our proposed model cuts crops like a human farmer. so it is designed with an arm having gripping ability in the end effector. This arm is origined from the upper portion of the gear box with a ball bearing based revolute joint. It will ensure its circular rotation using a servo motor. Another ball bearing based revolute joint is at the starting of the wrist part (white part in the figures 6) which will allow the cut crop to be put aside. This part is also of aluminum 2014 t-6 whereas for the finger plates and base plate of gripper there will be an additional portion of EPDM 70 durometer (70A) rubber material for ensuring a better frictional surface for gripping. EPDM is used for its environment friendly attitude, it works against abrasion.
The gripping model of arm is shown in figure 11 and 12. While searching for a tree, the grip will be opened and the open fingers will surround 10 inch portion.

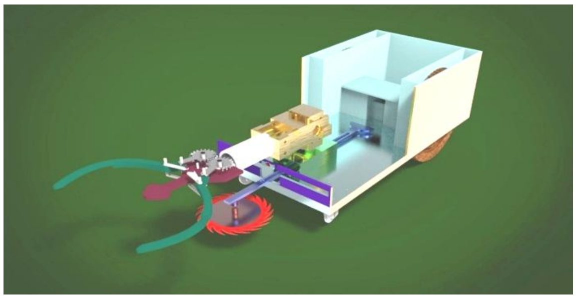

Fig.11 Farmer robot searching for crop in the crop field

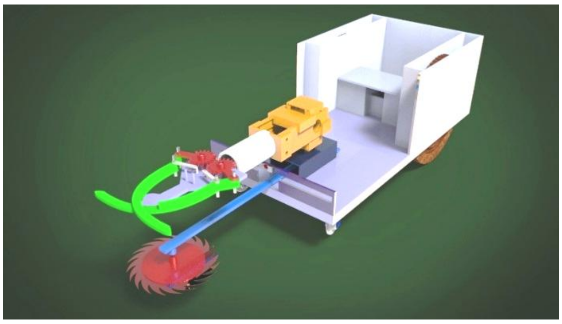

Fig.12 Robot farmer found crop and grip got closed and cutter comes

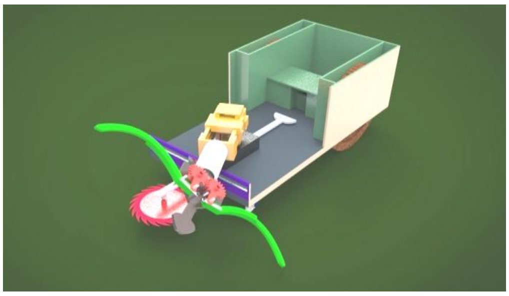

Fig.13 The manipulator turns left and opens grip to put the tree aside (Cutter is not rotating then)

When it senses a tree inside range, it will close its paw and with the help of an extended plate the grip will hold the cutting object tightly. The mechanism is run by 2 gears with a gear ratio 1:1

6. Electrical Parts

This part involves 4 DC and 3 servo motors, a distance measuring sensor, an arduino board, and electrical wires.

6.1 Motors

There are two motors at the rear wheels which drive the left and right wheels independently. The motor power ranges from 150W to 200 W. The torque of the motor is ranging from 50kg-cm to 80kg-cm. The higher torque rating enables the motors to drive the wheel at a higher efficiency. For DC motor, a motor driver IC (L293D) is used in the circuit diagram (Fig.16).

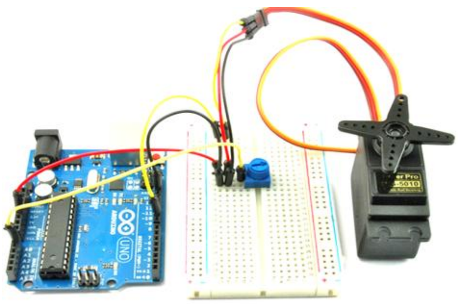

Fig.14 driving servo motor using Arduino board

DC Motor specifications:
1. Holding torque: 19N.m
2. Rated speed: 1500rpm

6.2 Distance measuring sensor:

For advanced measurement techniques distance Measuring Sensors are being used in robotics field. A distance measuring sensor measures where the nearest object is. Here we designed our robot with sharp distance measuring sensor. Unlike to a conventional sensor, it does not depend on color. It gives higher precision. Utilizing a focused beam, it indicates where an object is, or whether the object is in range.

Fig.15 Distance measuring sensor

Sensor specification:
Family: GP2Y0D02YK0F
Functionality: Digital
Range: 80 cm
Response Time: 39 ms

6.3 Arduino board

For controlling the system, an Arduino MEGA board is used. Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. The hardware consists of an open-source hardware board designed around an Atmega 2650 microcontroller. Current models consists of a USB interface, 6 analog input pins, as well as 14 digital I/O pins which allow the user to attach various extension boards.

7.0 Circuit Layout:

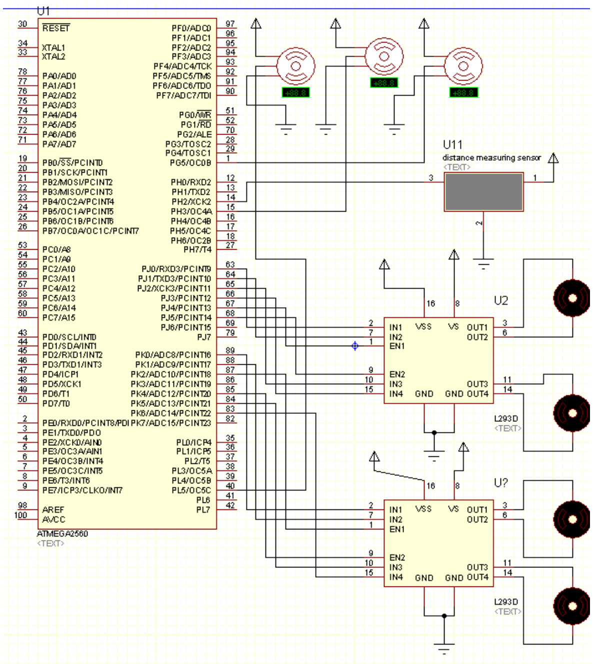

Fig.16 Circuit diagram of the system

The circuit is designed for Atmega 2560 microcontroller which is used in Arduino mega.

8.0 Program Algorithm (Control Loop)
Initialize sensor
Start left wheel motor clockwise and right rear wheel motor anti-clockwise (car moves forward)
If
Sensor detects obstacle, move up to limit (11 inches apart) and stop both motors
Else
Start both motors clockwise (car tends to turns right)
If
Sensor detects obstacle, stop motors and start left wheel motor clockwise and right wheel motor anti-clockwise up to limit (car moves forward) and then stop both
While
Both wheel motors stop (crop is inside gripper fingers)
Do
Start gripper motor on counter clockwise up to limit and stop (grip closed)
While
Gripper motor stops
Do
Turn pinion motor on up to limit and stop and start cutter blade motor on
While
Pinion motor turns off
Do
Turn revolute joint motor 1 (at base) counter clockwise on up to limit and stop (arm rotates in left direction)
While
Revolute joint motor 1 stops
Do
Turn revolute joint motor 2 (at elbow) clockwise on up to limit and stop (crop tends to get parallel to ground)
While
Revolute joint motor 2 stops
Do
Turn gripper motor on clockwise (crop is stored at the left side) and stop up to limit
While
Gripper motor stops,
Do
Wait 5 seconds and turn gripper motor counter clockwise on up to limit and stop and turn revolute joint motor 1 clockwise up to limit and stop and turn revolute joint motor 2 on counter clockwise up to limit and stop (arm is at initial position)
Start from the first again
If
no signal is found in 1 minuet
Then Stop

9. Design analysis and Simulation
Design analysis is studied and analyzed in solid works 2010 simulation platform.

9.1 Terminologies used in simulation
(1) Meshing
It is a very crucial step in design analysis. The automatic mesher in the software generates a mesh based on the global element size, tolerance, and local mesh control specifications. Mesh control helps us to specify different sizes of elements for components, faces, edges, and vertices. A mesh consists of one type of elements unless the mixed mesh type is specified. Solid elements are naturally suitable for bulky models. Shell elements are naturally suitable for modeling thin parts (sheet metals), and beams and trusses are suitable for modeling structural members.

(2) Von Mises Stress
The von Mises yield criterion suggests that the yielding of materials begins when the second deviatory stress invariant reaches a critical value. For this reason, it is sometimes named as the -plasticity or flow theory. It is part of a plasticity theory that applies best to ductile materials, such as metals.

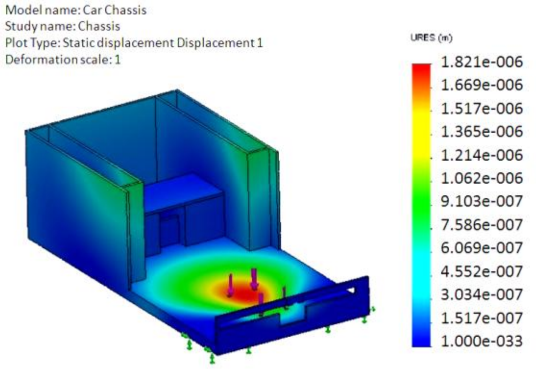

Fig.17 Static Displacement analysis (m)

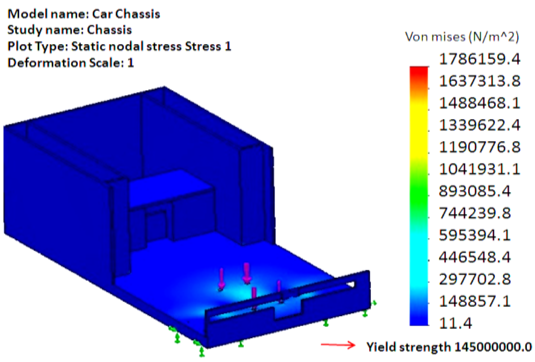

Fig.18 Von mises stress analysis

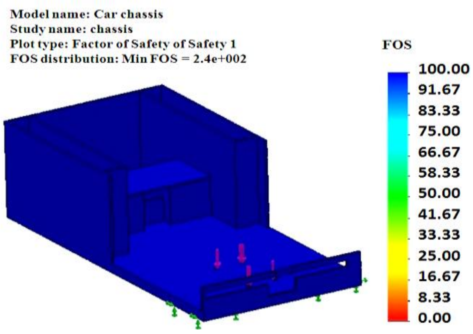

Fig.19 Factor of Safety (FOS)

(3) Factor of Safety (FOS)

FOS is the ultimate strength of a given material divided by an arbitrary factor of safety, dependent on material and the use to which it is to be put, gives the allowable stress.[5]

$$FS = \frac{S_{al}}{\sigma_{ap}}$$

Where,

S_{al} = Allowable strength

σ_{ap} = Applied stress (Allowable stress)

FS = Factor of Safety

10. Result and Discussion

The simulation analysis shows that the material selection allows a factor of safety of 240 for the different parts of the robot chassis which will carry the other parts. The displacement is nearly negligible and the maximum displacement is analyzed as 1.821 micro meter. The basic forces acting on the robot are mainly the weight force as the external force added by a paddy tree is very small. Through stress and strain analysis the model is simulated after meshing and no alarming deformation or excess stress is identified with the given material properties. So the design can be considered as stable. Yet, more analysis is required to produce this robot industrially depending on the environment, materials available, and crop type. On the basis of stated mechanism and material in our model we calculated that the total farmer robot will cost BDT 15,290 only.

Table 2 Material cost:

Sr. no	material	Amount	price	Final Price (BDT)
1	Aluminum 2014 t-6	17 kg	240 BDT/kg	4080
2	mahogany	.137 x10^-3	320 BDT/ Sq. meter	10
3	EPDM70 udometer	1/4 roll	12000/roll	3000
4	DC Motors	4	200 BDT/piece	800
5	Servo motors	3	800 BDT/ pc	2400
6.	Miscellaneous (machining, production)	-	5000	5000
			Total:	15,290

Table 3 Advantage over Traditional vehicles:

Sr. no.	Topic	Traditional vehicle	Robot farmer
1.	Power source	Diesel/gasoline engine	Runs with rechargeable battery
2.	Approximate cost	200000 BDT or more	15,290 BDT
3.	Physical involvement	At least 2 persons needed to operate	No physical involvement needed, Just monitoring is needed

11. Conclusion

In this paper, through utilizing new materials and mechanism we have integrated the advantages of a robotic manipulator, and an automated cutter to serve a single specific purpose of cutting operation in the field as a farmer robot. This design is compared with the traditional man operated vehicles and it is found that this is more cost effective and affordable for most of the farmers. Further research is required to improve it for serving the purpose of the farmers and to increase the production rate of the crops like paddy.

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