DESIGN AND ANALYSIS OF UGV WITH ROCKER BOGIE MECHANISM FOR LANDMINE EXTRACTION

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ABSTRACT

Landmines are one of the earliest & deadliest devices used in military to destroy enemy targets. Mines are deployed in various terrains and hence the extraction of mines could be a challenging task. Under such circumstances, an Unmanned Ground Vehicle (UGV) with a rocker bogie mechanism would be able to accomplish the given task. Hence, a UGV with rocker bogie mechanism has been designed for the purpose of landmine extraction. The designed UGV is driven by two motors. One motor mounted to the wheels is responsible for the linear movement and the other is responsible for the steering. The rocker bogie mechanism is a six wheel standard design which acts as the suspension system that works in tandem with the differential and helps in rolling and maneuvering of the UGV in all terrains. The robotic arms and end effectors are designed for the extraction of the land mine. The End effector has two tools viz. drill bit and robotic grip. The drill bit helps in drilling all around the mine and the grip picks up the mine from the pit. The UGV is designed based on various design calculations and modelled using Autodesk Fusion 360 Software. The 3D model is further analyzed using Ansys Workbench software by simulating the various loads acting on the critical joints. At the end of the study it was found that the designed model did not prove any kind of failure during the simulations.

Keywords: Gas Turbine, Aircraft, Mesh convergence, Mesh discretization, Energy norm, FEM.

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1. INTRODUCTION

Landmines are one of the earliest & deadliest devices used in military to destroy enemy targets. These are generally pressure sensing devices which get detonated by the change in pressure i.e. if the enemy target drives or steps over the device. Various designs are available by the virtue of its size, ability of blast radius, fragments thrown and so on. Landmines are easy to be deployed in sites. However, retrieval or removal of the same in post-conflict areas is a challenging task because mines are potentially two-edged weapons. Once they are deployed, they can be lethal to the side that laid them as well as to the enemy [1-3]. Various landmine detection & retrieval techniques have been developed viz. metal detectors, acoustic sensors, Infrared imaging systems, Prodders & Probes, Microwave techniques and so on. However, many of these techniques involve human intervention at a close range which could still be lethal. Further, mines are deployed in various terrains and hence the extraction of mines could be a challenging task, even with the usage of various landmine detection techniques currently available [4-6]. Under such circumstances, an Unmanned Ground Vehicle (UGV) with a rocker bogie mechanism would be able to accomplish the given task in any terrain. [7-8], the researchers focus on development of unmanned aerial vehicles also, to coordinate with the ground vehicle to guide and provide information of the coordinates of the location where landmine exists.

2. METHODOLOGY

The UGV must essentially be a rover which is capable of all terrain mobility due to various terrain and environmental conditions in which it would be required to operate. The UGV consists of the following major sub-systems:

1. Motor wheel sub-assembly
2. Rocker Bogie mechanism
3. Differential
4. Robotic arm
5. End effector

The motor wheel sub-assembly is responsible for powering up and movement of the UGV. Rocker bogie mechanism acts as the suspension of the vehicle and helps in rolling the wheels effectively in any terrain. The Rocker bogie mechanism along with the differential contributes to effective maneuvering of the vehicle and avoiding obstacles. The robotic arm and the end effector are the components that are responsible for the removal of the landmines. The drill bit, drills around the landmine and the robotic gripper mounted in the end effector assembly would be capable of removing the landmine safely, without triggering the same.

Figure 1: UGV with rocker bogie mechanism
2.1. Modelling
Autodesk Fusion 360 software has been used for the 3-D modelling of the UGV. The initial modelling was performed based on a conceptual thinking. However, later, the model was refined using the values or dimensions obtained from the calculations.

2.2. Motor Wheel Sub Assembly
The motor wheel sub assembly consists of two motors and one wheel. The primary motor is a high torque DC geared motor which is wheel mounted and is responsible for the linear motion. The secondary motor is a mega torque DC Servo motor. This is mounted at the top of the wheel mounting bracket as shown in Fig. 2. This provides the steering capability to the wheels. The secondary motor is mounted only to the front two and rear two wheels. The front two wheels turn in one direction while the rear two wheels turn in the opposite direction which gives a very low turning radius to the UGV.

![Motor Wheel Sub Assembly](image)

**Figure. 2:** Motor Wheel Sub Assembly

2.3. Rocker Bogie Mechanism
In order to overcome vertical obstacle faces, the front wheels are forced against the obstacle by the center and rear wheels which generate maximum required torque. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle and obstacle overtaken. Those wheels which remain in the middle, is then pressed against the obstacle by the rear wheels and pulled against the obstacle by the front till the time it is lifted up and over. At last, the rear wheel is pulled over the obstacle by the front two wheels due to applying pull force. During each wheel's
traversal of the obstacle, forward progress of the vehicle is slowed or completely halted which finally maintain vehicles center of gravity.

As per the research it is found that the rocker bogie system reduces the motion by half compared to other suspension systems because each of the bogie’s six wheels has an independent mechanism for motion which is essentially a motor mounted on or inside each wheel, inside so that it does not collide with the external terrain during its operation. The two front and two rear wheels have individual steering systems which allow the vehicle to turn in place as 0 degree turning radius [7].

2.4. Differential

A differential is a gear train with three shafts that has the property that the angular velocity of one shaft is the average of the angular velocities of the others, or a fixed multiple of that average [11]. The differential is the component that maintains the stability of the UGV, without allowing it to topple due to the forces acting on the various kinematic linkages.

The differential gearbox designed is a simple three-gear differential. Two gears connect to the two rockers and the third (middle) gear connects to the body. During the working of the UGV, if one rocker up tilts up due to the change in terrain, the gears of the differential rotate to ensure that the other rocker tilts down. This ensures the stability of the UGV.

2.5. Robotic Arm

The robotic arm has four degrees of freedom capable of pick and place operation. The links are made hollow to provide rigidity and reduce the overall weight, thereby reducing the torque requirement of the motor that operates the arm. Two DC motors are used to actuate the links of
the robotic arm. One motor is mounted at the base and the other motor is mounted at the joint. The DC motors transmit force to a gear train which in-turn satisfies the torque requirement. Spur gears are used as shown in the Fig. 5 for the movement of the links. Design calculations were performed for each of the gears.

2.6. End Effector
The end effector is mounted at the end of the robotic arm. It is responsible for the extraction of the land mine. The end effector assembly is provided with two tools viz. drill bit and robotic gripper.

![Figure. 6: End Effector with Gripper and Drill bit](image)

The gripper has been given two degrees of freedom and the drill bit has been given one degree of freedom. The gripper has been given rotational freedom about the horizontal axis and the vertical axis. The drill bit has been given rotational freedom on the horizontal axis. The whole end effector is free to rotate about the axis through the center of the plane of the front view.[9]

3. CALCULATIONS
The major subsystems further consist of different components essential for the effective working of the mechanism. Various calculations essential for effective design were carried out.

3.1. Wheel Torque Calculation
The following consideration were made based on the study of various designs and availability of standard components:

1. No. of wheels in UGV : 06 Nos.
2. Gross vehicle weight (GVW) : 24 Kg
3. Radius of each wheel (Rw) : 0.035m
4. Max. gradient of slope (α) : 450
5. Max. linear velocity (Vmax) : 1.5 ft/s
6. Surface friction co-eff. (Crr) : 0.30
7. (Crr of sand is considered)
Table 1: Calculation of Wheel Torque required

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Equation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling Resistance (RR)</td>
<td>GVW x Crr</td>
<td>7.2 Kg</td>
</tr>
<tr>
<td>Grade Resistance (GR)</td>
<td>GVW x Sin α</td>
<td>16.97 Kg</td>
</tr>
<tr>
<td>Acceleration Force (FA)</td>
<td>(GVW x Vmax) / 32.2 ft/s² x 1s</td>
<td>1.118 Kg</td>
</tr>
<tr>
<td>Total Tractive Force (TTE)</td>
<td>RR+GR+FA</td>
<td>25.288 Kg</td>
</tr>
<tr>
<td>Wheel Torque (Tw)</td>
<td>TTE x Rw x RF</td>
<td>97.35 Kg-cm</td>
</tr>
</tbody>
</table>

However, the standard motor torque available is 120 Kg-cm and the same has been considered for the design of the UGV.

3.2. Robotic Arm Torque requirement Calculation

![Free body diagram of Robotic Arm](image)

Figure. 7: Free body diagram of Robotic Arm

Based on the optimum design of the UGV robotic arm, the following values were taken in the calculation of torque requirement.

For link 1 of robotic arm:
- Mass ‘M1’ = 1.2 Kg;
- Length of the link ‘L1’ = 0.3m
- Centre of mass of link ‘COM1’ = 0.15m

For link 2 of robotic arm:
- Mass ‘M2’ = 1 Kg
- Length of link ‘L2’ = 0.25m
- Centre of mass of link ‘COM2’ = 0.125m
- Mass at the joint ‘Mj’ = 0.03 Kg
- Mass of object i.e. Landmine Mass ‘Mo’ = 4 Kg
- Joint acceleration ‘ACC1 = ACC2’ = 50 °/s²
Efficiency of the system ‘η’ = 90%

\[ T_1 = \left\{ \left[ (M_1 \cdot \text{COM}_1) + (M_j \cdot L_1) + (M_2 \cdot (L_1 + \text{COM}_2)) + (M_1 \cdot \text{COM}_{12}) + (M_j \cdot L_{12}) + (M_2 \cdot (L_1 + \text{COM}_2)^2) \right] \cdot (\text{ACC}_1) \cdot \left( \frac{\pi}{180} \right) \right\} \div (1/\eta) \]

\[ T_1 = 4.504 \text{ Kg-m} = 450.4 \text{ Kg-cm} \]

\[ T_2 = \left\{ \left[ (M_2 \cdot \text{COM}_2) + (M_0 \cdot L_2) + (M_2 \cdot \text{COM}_{22}) + (M_0 \cdot L_{22}) \right] \cdot (\text{ACC}_2) \cdot \left( \frac{\pi}{180} \right) \right\} \div (1/\eta) \]

\[ T_2 = 1.508 \text{ Kg-m} = 150.8 \text{ Kg-cm} \]

The above calculated values of T1 and T2 give us the torque required to move the links of the robotic arm when a landmine is held in the end effector, at an effective link acceleration of 50 °/s². It can be inferred that these values of torque are extremely high for any normal motor to supply. Hence, a certain gear combination to provide the necessary output torque to the robotic arm by applying speed reduction gear ratio has been designed.

### 3.2.1. Robotic Arm Gear Ratio Calculation

The positions of the gears are as shown in the Fig.5. A speed reduction gear setup has been designed to amplify the torque characteristics. The torque transmitted by a gear is directly proportional to the number of teeth on the gear and can be given by the relation below:

\[ \frac{T_{\text{in}}}{T_{\text{out}}} = \frac{N_{\text{in}}}{N_{\text{out}}} \]  (1)

The required torque for each link is as follows:

T1 = 450.4 Kg-cm ≈ 510 Kg-cm (For ease of calculation)

T2 = 150 Kg-cm

The available torque for each link based on selected motors:

T1av = 255 kg-cm

T2av = 120 kg-cm

The gear ratio and number of teeth can be found using equation (1):

For Link 1

Gear ratio = [510/255] = 2:1

Number of teeth on driver gear = Nin = 20 teeth

Number of teeth on driven gear = Nout = 40 teeth

For Link 2

Gear ratio = [150/120] = 1.25:1

Number of teeth on driver gear = Nin = 20 teeth

Number of teeth on driven gear = Nout = 25 teeth

### 3.3. Robotic Arm Spur Gear Design Calculation

Two sets of gear systems are required to conduct the speed reduction or torque magnification, according to the earlier calculations. For ease of manufacturing, the gears are selected such that their numbers of teeth are 20, 40 and 20, 25.

In order to manufacture the gears, the various technical specifications of the gear system need to be calculated. With the help of the mechanical design data handbook, the specifications of each gear can be calculated after making a few assumptions.

Pressure Angle = 20° Full Depth Involute System.

Module of gear ‘m’ = 4mm

Thus Zmin or Nmin= 18 teeth
Table 2: Robotic Arm Gear Nomenclature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
<th>20 Teeth (mm)</th>
<th>40 Teeth (mm)</th>
<th>25 Teeth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addendum</td>
<td>Module (m)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Dedendum</td>
<td>1.157 m</td>
<td>4.628</td>
<td>4.628</td>
<td>4.628</td>
</tr>
<tr>
<td>PCD</td>
<td>m x Z</td>
<td>80</td>
<td>160</td>
<td>100</td>
</tr>
<tr>
<td>Outside diameter</td>
<td>(Z+2) m</td>
<td>88</td>
<td>168</td>
<td>108</td>
</tr>
<tr>
<td>Tooth Thickness</td>
<td>1.571 m</td>
<td>6.284</td>
<td>6.284</td>
<td>6.284</td>
</tr>
<tr>
<td>Total Depth</td>
<td>2.157 m</td>
<td>8.628</td>
<td>8.628</td>
<td>8.628</td>
</tr>
<tr>
<td>Minimum Clearance</td>
<td>0.157 m</td>
<td>0.628</td>
<td>0.628</td>
<td>0.628</td>
</tr>
</tbody>
</table>

3.4. Calculations of standard Rocker Bogie system

The DC motor used for each of the six wheels has the following specifications based on the requirement and availability:

- Speed, \( N = 300 \) RPM
- Torque, \( T = 30 \) kg-cm
- Diameter, \( D = 70 \) mm

Overall size of the vehicle can be restricted to a length of 500mm to reduce cost of manufacturing. Hence, the wheel base (distance from the center of the front wheel to that of rear wheel) can be calculated as follows:

\[ L_w = 500 - (2 \times \text{Radius of wheel}) = 430\text{mm} \]

For the given geometry of the rocker bogie system, we can find the length of the links using basic Pythagorean Theorem and geometry.

\[
LL = \frac{L_w}{\sin \theta} = \frac{0.5 \times 430}{\sin 45°} = 304.056 \text{mm} \approx 304\text{mm}
\]

Therefore, \( AB = BC = 304\text{mm} \)

\( MN = AM = [0.5 \times AB] = 152\text{mm} \)
The height of the rocker bogie system above ground plays a great role in the stability of the entire system. As the height of the rocker bogie increases, the Center of Gravity of the vehicle raises, which in-turn decreases the lateral stability of the vehicle.

\[ H = BC^2 - NC^2 = 3042 - 2152 = 214.92 \approx 215 \text{mm} \]

Adding the increase in height due to the wheel mount, gives the actual height of the entire system,

\[ H = 215 + [(75+11.5+12)] = 313.5 \text{mm} \]

The track width of the vehicle is the distance between the center of the wheels on the left and right of the body. It can be calculated by using a standard rocker bogie mechanism formula as shown below [11].

\[ Tw = \text{Static Stability Factor (≈1) x 2 x H} = 627 \text{mm}. \]

4. SIMULATION & ANALYSIS

Static Structural analysis of the UGV has been carried out in order to study the effects of the steadily applied loads. The wheel mounts and the robotic arm links are the components of the system that would be subjected to high static loading conditions. The deformations, stresses and strains of these vital components have been studied. ANSYS Workbench simulation software has been used for the simulation. [10]

4.1. Wheel mounts

The motor wheel sub-assembly is as shown in Fig.2. The suspension mounting bracket is the intermediary component that connects the rocker bogie suspension system and the motors that are further connected to the wheels. This bracket takes up the load of the UGV before transferring it to the wheels and hence has been analyzed.

Two conditions have been considered for the analysis. In the first condition of force where the UGV weight is considered, the weight is applied as a point load on the slot for the bolt on the vertical faces. The four bolt holes on the horizontal surface act as a fixed support as shown in Fig. 8. GVW is calculated as 24 Kg (240 N).

![Figure 9: Deformation & Stresses: Condition 1](image-url)

In the second condition of force of reaction and force applied by the ground on the UGV, the forces act upwards. In this condition, we neglect the force by the ground on the UGV due to surface irregularities. Thus the force is assumed to act on the four bolts as an upward force, while the fixed support is the hole on the vertical surface as shown in Fig. 9.
4.2. Robotic Arm Links

In the case of the robotic arm, there are two links. One connected to the base by a revolute joint Viz. link 1 and the other connected to the first link via a revolute joint viz. link 2. The maximum deformation and the maximum stress will occur when the links are in the horizontal position or when the load is exactly perpendicular to the link length.

In this case, the combined weight of the end effector, the landmine and the link is considered as the load on the holes where the link 1 is connected to link 2 via a revolute joint. The pin holes where the link 1 is connected to the robotic arm base is considered as a fixed support in order to find the maximum possible deformation in the first link.

The overall load ‘m’ is found using the principle of balancing of moments using the length and weight of links calculated earlier.

\[
(4 \times 550) + (1 \times 125) + (1.2 \times 150) = m \times 300
\]

Therefore, \( m = 9.35 \) kg, i.e. 92N.
The weight of the end effector and the landmine is considered as the load on the pinhole where the link 2 is connected to the end effector via a revolute joint. The pin holes where the link 2 and link 1 are connected is considered as a fixed support in order to find the maximum possible deformation in the second link.

![Figure 13: Robotic Arm: Link 2](image13.png)

The overall load ‘m’ is found using the principle of balancing of moments using the length and weight of links calculated earlier.

\[(4 \times 250) + (1 \times 125) = (m \times 250)\]

Therefore, \(m = 4.5\) kg, i.e. 45N.

![Figure 14: Deformation & Stress: Robotic Arm Link 2](image14.png)

**4.3. Rocker Bogie Mechanism Links**

The rocker bogie consists of the Rocker that works on the rocking aspect of the larger links on each side of the suspension system. These rockers are connected to each other and the vehicle chassis through a differential.

The forces that act on the suspension system are the reaction forces i.e. the weight of the vehicle acting upwards and the force due to surface irregularities acting upwards. In this study we neglect the forces due to surface irregularities.
The force on each wheel mount due to the reaction is 240N/6wheels, i.e. 40N per wheel. Thus the net force acting on the rocker end pin is 40N and the net force at the rocker-bogie pivot point is 80N. Using these two forces and a fixed support at the rocker to UGV pivot, the maximum deformation and the von mises stress are simulated.

The bogie link is the link that has a wheel mount at both ends. The bogie link is connected to a pivot on the rocker.
5. RESULTS & DISCUSSION

The simulation of the various links using ANSYS Workbench software provided the results as shown below:

Table 3: Simulation Results

<table>
<thead>
<tr>
<th>Item</th>
<th>Max. Deformation (m)</th>
<th>Von Mises Stress (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel Mount Condition 1</td>
<td>0.0013421</td>
<td>9.6044e8</td>
</tr>
<tr>
<td>Wheel Mount Condition 2</td>
<td>0.0013421</td>
<td>9.6044e8</td>
</tr>
<tr>
<td>Robotic Arm Link 1</td>
<td>0.0011065</td>
<td>2.0271e8</td>
</tr>
<tr>
<td>Robotic Arm Link 2</td>
<td>0.00030146</td>
<td>8.4416e7</td>
</tr>
<tr>
<td>Rocker Link</td>
<td>5.0253e-5</td>
<td>8.2148e6</td>
</tr>
<tr>
<td>Bogie Link</td>
<td>6.6028e-6</td>
<td>4.672e6</td>
</tr>
</tbody>
</table>

It can be understood from the simulation results that there have been no failures detected any of the components and hence the design is safe.

6. CONCLUSION

Clearing landmines in post-conflict areas is still one of the most important humanitarian problems to be solved. The time and resources needed to clear such areas by using only traditional and manual methods would be enormous. Hence, there is a great demand and importance of unmanned technologies being used for the purpose of retrieving and disposing landmines. The UGV designed could be an effective solution for the aforesaid problem. The modelling and
simulation of the concept and design prove that the discussed model could be taken to the next stage of manufacturing.

REFERENCES


