Design and Development of Six-Wheeled Multi-Terrain Robot

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***Abstract*— In the past few decades demand for Multi Terrain Robot applications have been increased significantly. These robots can be employed for the purpose of security surveillance and rescue purposes in the remote areas. In remote areas the terrain is not uniform and hence stability of the robot becomes a challenging task. In this paper, a new design is proposed for the mobile robot, which aims to perform monitoring task while running on different types of terrain or real time physical environment in balanced way. A six-wheeled multi terrain robot has been developed which has capability to run in rocky and sandy areas, to move on inclined plane and to climb on stairs.**

Keywords—Multi-terrain robot, Rocker, Suspension system, Survellience, Simulation

I. Introduction

Demand of Multi Terrain Robot applications have been increased significantly in the past few decades. Mobile robotics emerge out as the most popular interdisciplinary research field for the purpose of security surveillance (where mobile robot monitors some particular area or field), path finding in complex areas, research platform for mobile robot path planning and planet exploration like MARS rover. Particularly, the development of remotely or semi- remotely operated robot for surveillance is strongly required. In remote areas the terrain is not uniform and hence balancing of the robot becomes a challenging task.

Various designs have been explored by different researchers for the multi terrain robots. The shrimp rover [1] discussed approach for kinematic modeling of the robot traversing uneven terrain. They also presented motion study for step climbing. Nagatani et al [2] discussed development and control of six wheeled robot with rocker structure for rescue purpose. Out of six wheels, two pairs of wheels in front are formed as actuated rocker structures. They proposed that this wheel configuration can achieve "active load equalizer" for controlling the robot on uneven terrain. Krebs et al [3] proposed a software tool for performance optimization of All-Terrain Robot based on a quasi-static approach including optimization of the friction coefficients to model and evaluate the rover. Table 1 summarizes a comparison of all terrain robots developed by different researchers.

Table 1: Comparison chart between the previous All Terrain Robot

	Shrimp [1]	Talon [4]	Packbot [5]	CoMoRAT [6]
No. of motors	8	4	4	4
No. of wheels	6	6+ track belt	6+dual track belt	4+ track belt
Dimensions (mm)	639x428x278	864x572x472	686x406x178	300x500x80
Weight (Kgf)	5.4	52	10.89	-
Payload (Kgf)	3	12-45	-	15
Max. speed (m/s)	0.35	2.3	2.6	1
Turning mechanism	Front and rear wheel	Caterpillar	Caterpillar	Caterpillar
No. of motor in turning mechanism	2	0	0	0
Capability	Stair climbing	All terrain robot	All terrain robot	-
Maneuverability	4	4	4	4
Suspension	Self-adaptive	No	No	No

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In this paper, a new design is proposed for the mobile robot, which aims to perform monitoring task while running on different types of terrain or real time physical environment in balanced way. The proposed model has six wheels with semi-circular rocker mechanism (fig. 1). The six-wheeled multi terrain robot has capability to run in rocky area, sandy area, on inclined plane and on stairs.

Fig. 1: Proposed Six-Wheeled Multi Terrain Robot (SWMTR)

II. Robot Design

To move on all terrain, mechanism of the robot plays important role. Researchers have used caterpillar [4,5,6], or both front and rear wheels [1,2] for turning mechanism. The proposed design uses a combination of caterpillar differential steering and worm and sector steering mechanism for turning. In this mechanism friction losses are less than Talon [4] and Packbot [5] but greater than Shrimp [1] and the robot designed by Nagatani et al [2] but the number of actuators are lesser.

A. Mechanism and structure of six-wheeled multi terrain robot

The mechanical structure of proposed robot consist of six high frictional rubber wheels, two semi-circular rocker structure, one connecting rod, and one rear chassis. The CAD model of the proposed mechanism is shown in fig. 2. The robot mechanism has lateral symmetry. The 2+1 groups of wheel mechanism are laterally situated. The semi-circle rocker wheels are driven simultaneously by one actuator and the rear wheels are driven individually for getting more power. The total degree of freedom of six-wheeled multi terrain robot is ten which provide more flexibility in rough terrain.

For climbing stairs the wheel diameter should be more than the maximum step-height. Hence, the wheel diameter is selected as 11 cm considering normal stair height of 6 cms. The front and middle wheel are connected by a semi-circular rocker arm, and two pairs of them are located at the front with connecting rod at the front of the robot. The semi-circular rocker joint moves independently to climb stairs and to adjust the height difference on uneven terrain.

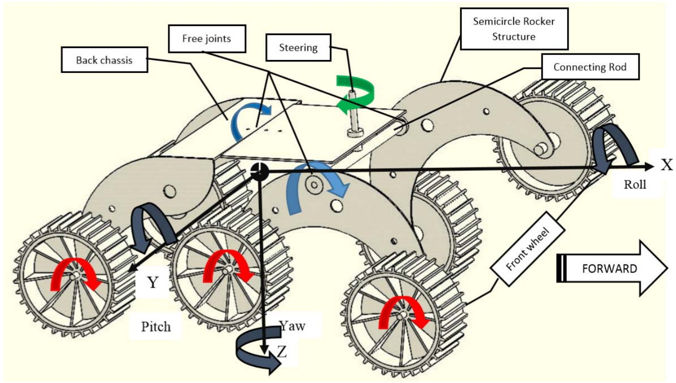

Fig. 2: CAD model of proposed six-wheeled multi terrain robot

Semicircular structure has advantage in terms of transfer of load from front wheel to rear wheel in case front wheel collides with some object.

B. Parameters of Proposed Design

The proposed parameters of six-wheeled multi terrain robot are calculated based on the task to perform, sizes of obstacles expected. The proposed parameters are:

- Number of wheel: 06
- Total weight of the robot: 6 Kgf
- Dimensions: 500mm×310mm×240mm (l×w×h)
- Diameter of the wheel: 120 mm
- Width of wheels: 50 mm
- Distance between two wheels: 190 mm
- Height from ground to base body: 195 mm
- Number of actuator: 05
- Payload: 10 Kgf
- Maximum speed: 0.5 m/s

C. The Degree of Maneuverability of Multi-Terrain Robot

The degree of maneuverability (δ_M) of a robot is its ability to move in the terrain. It is a combination of degree of mobility (δ_m) and degree of steerability (δ_s).

$$\delta_M = \delta_m + \delta_s \quad (1)$$

For the proposed MTR:

$$\delta_m = 2 \text{ (x and y direction movement)} \quad (2)$$

$$\delta_s = 1 \quad (3)$$

Hence, $$\delta_M = 2 + 1 = 3 \quad (4)$$

D. Semi-circular rocker mechanism:

A semi-circular mechanism based on design by [3] has been chosen to move robot on stairs. The mechanism is shown in Fig. 3. The ratio between a:b in semi-circle rocker mechanism is set as 3:5 (optimized using simulation) as compared to 1:3 [3]. This is due to change in the design proposed, we are using semi-circular rocker while Nagatani, et al used a simple bar.

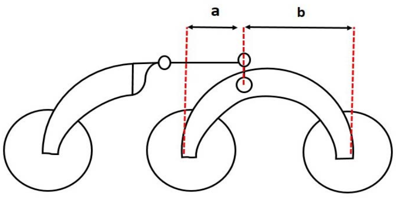

Fig. 3: Ratio between a and b.

Semi-circular rocker mechanism helps up in getting better bounce up of front wheel when moving on rough bouncy area, and climbing the stairs like shape. When the front wheel of the robot touches the stair or inclined terrain (here we take stairs as an example) it will bounce up, and the middle and rear wheel will push the robot and provide locking condition to avoid pull back. When front wheel climb up, the front and rear wheel will support the middle wheel for climbing the stairs. Similarly the front and middle wheel will support the rear wheel. This is due to semicircular link is hinged at a point and when wheel collides with object it turns the link about the hinge point while maintaining the height of robot base from the ground.

Semi-circular rocker structure provides:

- Capability of distributing the robot's front wheel load to middle wheel while climbing up the stairs, stone or any obstacle.

- At the same time it also provides greater stiffness to the structure.

The rubber tyre provides high frictional force to grip the surface in climbing the stairs, moving in rough terrain, and bouncing the semi-circle rocker mechanism.

III. MAXIMUM MOTOR TORQUE REQUIREMENT

For driving the robot, motors need to be selected based on the torque requirements. Torque calculations are carried out both in static as well as dynamic conditions.

The total mass (m) of robot is considered as 6.8 Kg, including mass of wheels, gears and all motors. Weight of single wheel (m_w) is considered as 0.5 Kg. A model has been developed in Solidworks and analyzed. From the CAD model developed, center of gravity (CG) is found to be located at longitudinal center (x=38/2 cm) and lateral center and at a height of 9.906 cm from the ground. Friction coefficient (μ) between the rubber wheel and hard surface is assumed to be approximately 0.4.

Sample torque calculations are discussed here.

1. Torque requirement on inclined plane (under static condition):

   For this it is considered that MTR is standing on a plane with 30° of inclination. Forces can be calculated as

$$F_{Total\ (static)} = f_{friction} + mg.\sin\theta \quad (5)$$

$$F_{Total\ (static)} = \mu \times F_n + mg.\sin\theta \quad (6)$$

From the above equation total force is calculates as 58.06 Kgf and the corresponding torque requirement for this force is 348.3 Kgf-cm. If torque requirement is considered to be equally distributed on each motor, than rear wheel torque required will be 87.10 Kgf-cm and front and middle wheel torque required will be 43.54 Kgf-cm.

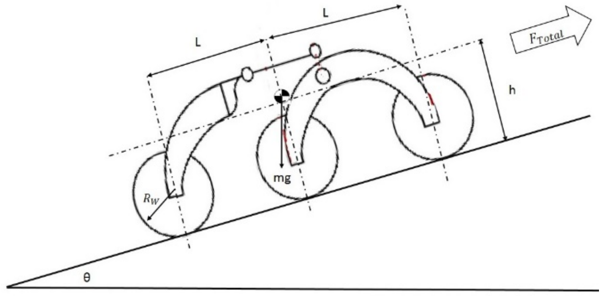

Fig. 4: Forces on MTR in inclination

2. Torque requirement on inclined plane (under dynamic condition):

Same case 1 has been analyzed under dynamic condition, considering 2 second desired acceleration time (t_a) and 0.5 m/sec of speed. Total force is combination of rolling resistance, grade resistance and acceleration force.

$$F_{Total(Dyanamic)} = R_{Rolling} + R_{grade} + F_{accelaration} \quad (7)$$

a. *Rolling Resistance:* Rolling resistance is the force required to propel a robot in terrain, which is defined as:

$$R_{Rolling} = \text{mass of Robot} \times \text{surface friction} \quad (8)$$

   Friction considered in this case as 0.15 for soft sand correspondingly, rolling resistance force comes out to be 1.05 Kgf.

b. *Grade Resistance:* Grade resistance is the force required to move a robot in inclined terrain (maximum 30°of inclination), which is given as:

$$R_{grade} = mass\ of\ Robot \times \sin\theta \quad (9)$$

   This comes out to be 3.5 Kg force.

c. *Acceleration Force:* Acceleration force is the force required to accelerate a robot from initial zero speed to full speed i.e. 0.5 m/sec in a desired time 2 second.

$$F_{accelaration} = {(m \times v_{full})}/{(9.8 \times t_{a})} \quad (10)$$

   Acceleration force is calculated as 0.179 Kgf.

Based on above calculations, total force is calculated as 4.73 Kgf. Corresponding, wheel motor torque can be calculated as:

$$T = F_{Total(Dyanamic)} \times R_w \times R_f \qquad (11)$$

Where, Resistance factor (R_f) should be chosen between 1.10 and 1.15.

So the total torque requirement under the dynamic condition is 31.21 Kgf-cm.

3. *Torque requirement on stairs:* The maximum step height (h_{step}) considered as 8 cm.

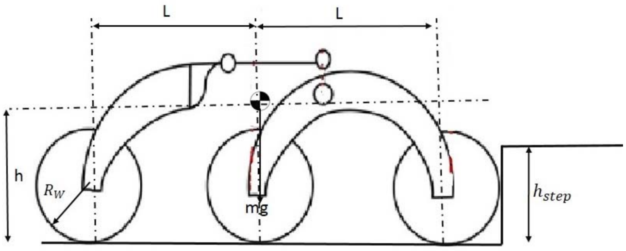

Fig. 5: Forces on MTR in Steps

For the stairs force required is given as

$$F = \frac{4mgL - L}{(2L + R_w) \times \mu} = 265.03 \text{ Kgf}$$

Corresponding torque required is 1770 Kgf-cm if all joints are fixed.

IV. Dynamic Simulation Analysis of Multi-Terrain Robot

The model is dynamically simulated on ADAMS® software to analyze requirements for torque under dynamic conditions. Two cases were considered for the analysis:

1. Climbing on 30° incliend surface and
2. Climbing on 6 cm step,

In both the cases coefficient of friction between wheel and terrain is asumed as 0.4 and angular velocity of all wheels is considered as 314 rpm.

A. Simulation Analysis of MTR on Inclined Terrains

The Fig. 6, Fig. 7, and Fig. 8 shows the torque requirement for front, middle and rear wheel on MTR. Sufrace torque for individual front, middle and rear wheel is obtained as 7.5 Kgf-cm, 6.75 Kgf-cm and 4.75 Kgf-cm which gives a sum of 38 Kgf-cm as compared to theoretical value calcualted as 31 Kgf-cm in section III (c). In this case rocker mechanism does not paly any role.

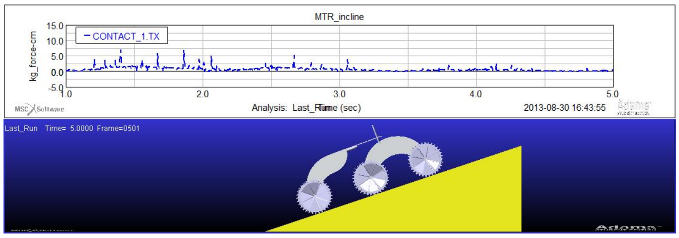

Fig. 6: The contact torque between front wheels and ground in inclination

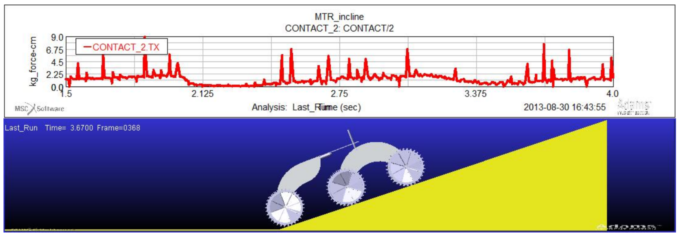

Fig. 7: The contact torque between middle wheels and ground in inclination

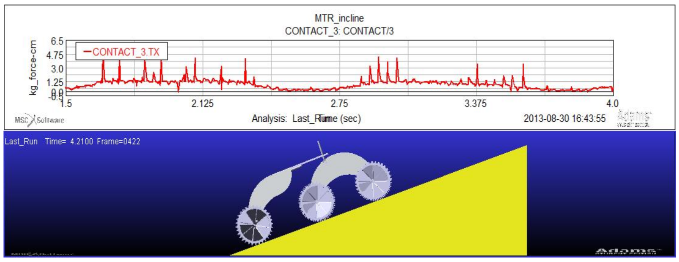

Fig. 8: The contact torque between rear wheels and ground in inclination

B. Simulation Analysis of MTR on Stairs

Next, simulation was carried out for climbing on stairs. In this case rocker mechanism plays an important role. Results are presented for both the cases in Fig. 9 to 13.

1. *Simulation Analysis of MTR on Stairs without Semi-circular Rocker Mechanism*

   When we simulate the MTR without semi-circular rocker mechanism, we found the contact torque between wheel and ground is too high. The maximum contact torque between wheel and ground is 180 Kgf-cm for front wheel (Fig. 9) and 1000 Kgf-cm for rear wheel (Fig. 10).

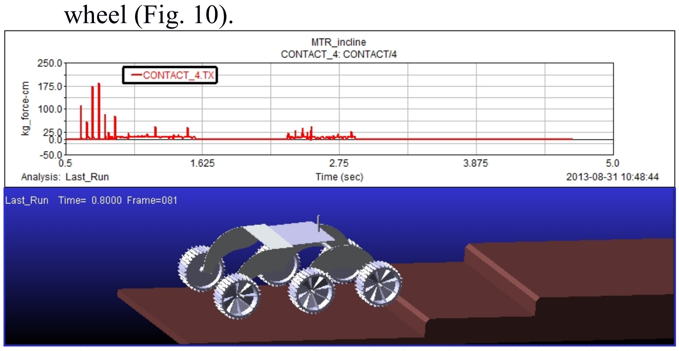

Fig. 9: The contact torque between front wheels and ground when climbing stairs without semi-circular rocker mechanism.

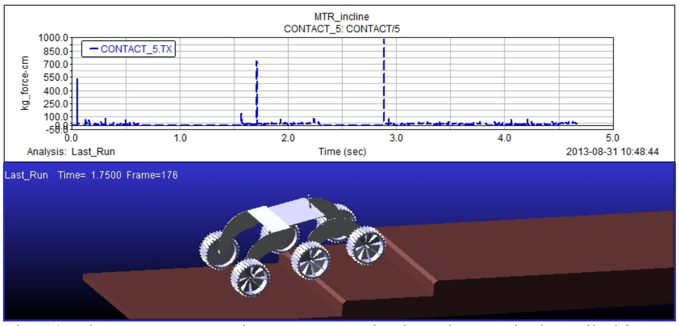

Fig. 10: The contact torque between rear wheels and ground when climbing stairs without semi-circular rocker mechanism.

2. *Simulation Analysis of MTR in Stairs with Semi-circular Rocker Mechanism*

Silmilarly when we simulate the MTR with semi-circular rocker mechanism, we found the contact torque between wheel and ground is very small as compare to previous simulation result and theoritical result. The maximum contact torque between wheel and ground is 20 Kgf-cm for front wheel(Fig. 11), 60 Kgf-cm for middle wheel (Fig. 12) and 25.1 Kgf-cm for rear wheel (Fig. 13).

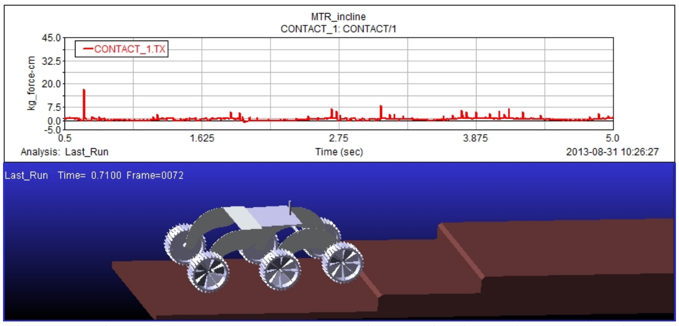

Fig. 11: The contact torque between front wheels and ground when climbing stairs with semi-circular rocker mechanism

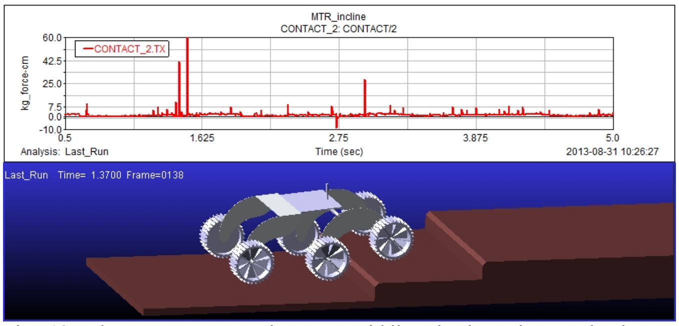

Fig. 12: The contact torque between middle wheels and ground when climbing stairs with semi-circular rocker mechanism.

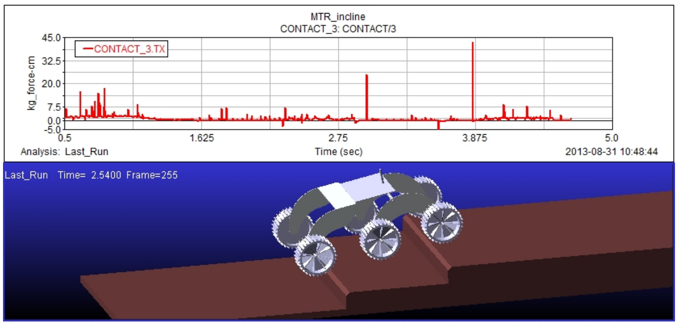

Fig. 13: The contact torque between rear wheels and ground when climbing stairs with semi-circular rocker mechanism.

V. RESULT

Based on the torque calculations and dynamic simulation for locomotion, Maxon motors with 200 Kgf-cm (maximum) stall torque at maximum limited stall current of 4 Amp are found to be suitable for all the wheels. Same capacity motors are chosen for the purpose of interchangeability.

Robot has a capability to move in roll angle in X-axis, yaw angle in Z-axis, and pitch angle in Y-axis, which has complete our suspension requirements. So, for every surface wheel always touched with the surface and provide its maximum traction to the robot.

Fig. 14: Real time testing snapshot of MTR on Stone

Fig. 15: Real time testing snapshot of MTR on Stairs

Fig. 16: Real time testing snapshot of MTR on Rough terrain

From the experiments we found some limitation of MTR while running in different terrain.

1. For stairs climbing the maximum step size would be 6 cm and same condition is applicable for other obstacle like stone or bumpy area.
2. The maximum inclination of surface where robot can run depends on torque of motor and traction between wheel and ground. Through software based analysis and real world testing, the maximum inclination that robot can climb was found to be 30°.

The modes of operation of six-wheel Multi Terrain Robot (MTR) are Auto-Pilot mode, Manual mode and Sleep mode. In first two modes, robot moves either automatically by using path planning or manually under the control of operator. Where as in sleep mode, the robot has no motion. All the actuators and sensors except the Camera are switched off during sleep mode to save on power while keeping the monitoring on.

VI. CONCLUSION

In this paper, we have developed a prototype of six-wheeled multi terrain robot. In this robot we achieve good terrainabilty to run on different types of terrain with great ease.

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