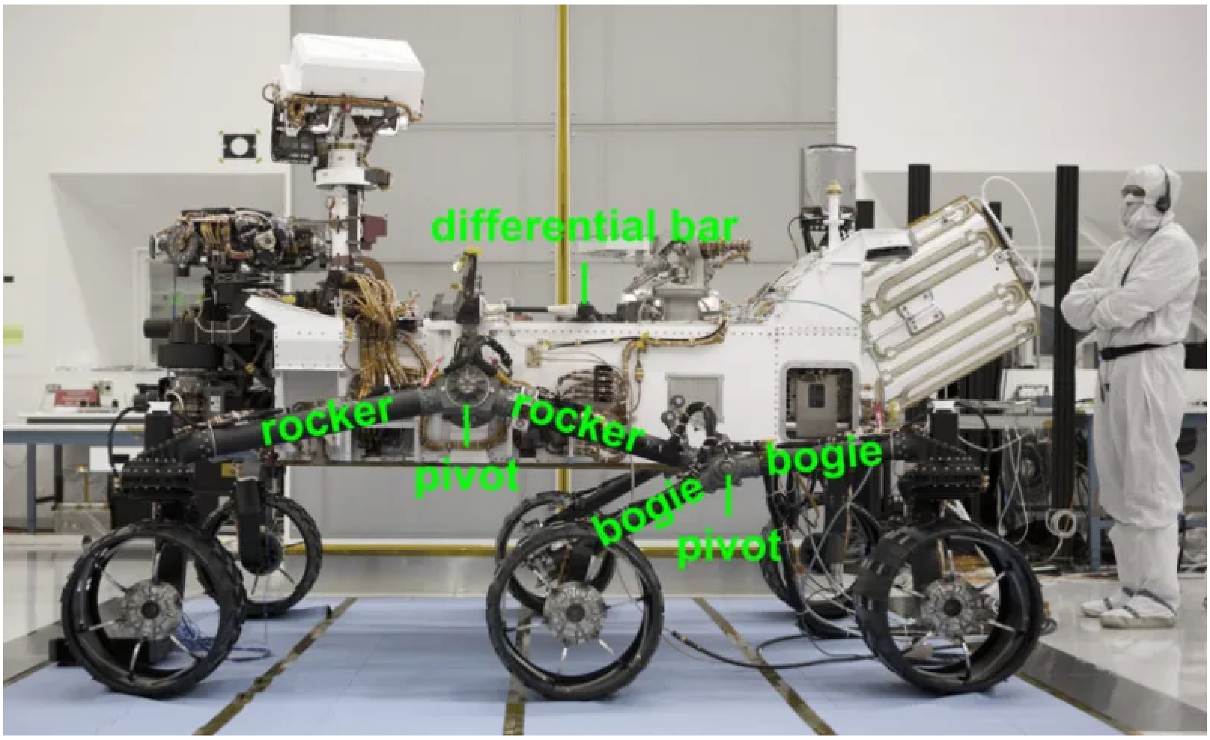
21/05/2020

Rocker bogie suspension

1. All rovers that have landed on mars are 6 wheeled rocker bogie systems.
2. The rocker bogie suspension can surmount obstacles head on that are larger than a wheel diameter because it uses an extra set of wheels to provide more forward thrust.
3. Typically a four wheeled rover can not climb obstacles larger than a wheel radius because the rear wheels do not have enough traction.
4. The extra wheels also reduce the normal force on each wheel by about 1/6 the weight of the rover.



22/05/2020

5. Each side of the suspension has two links, a main rocker and a forward bogie.

6. Making all wheels steerable will increase the movement flexibility of the rover and will help in performing crabbing maneuvers.

Related papers
https://drive.google.com/open?id=1WIH4fH89T2wI3QZQaLh2V5ffces5Rfnf
https://drive.google.com/open?id=1-HShnPeNCBrMwHbygRxv3M5DhKVMtS-F
https://drive.google.com/open?id=1TzIkcYIMueKSIW8QFLtWjCklzhpanwTj

Summary of papers

23/05/2020

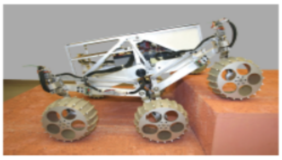
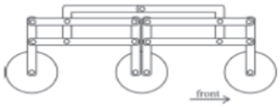
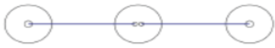
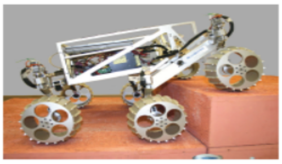
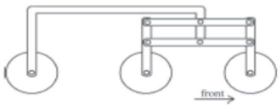
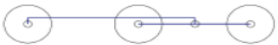
Characterization and Comparison of Rover Locomotion Performance Based on Kinematic Aspects

Introduction

This paper describes the continuation of the rover comparison based on the aspect: kinematics.A kinematic model can provide valuable information because the ability of articulated rovers to adapt to uneven terrain makes it difficult to relate rovermotion to wheel motion and requires the wheels to move at different speeds.This work's main focus lies on the development of a metric that helps characterizing the kinematic potential of different suspension types.Kinematics are used to calculate the optimal velocity distribution depending on the rover's state in rough terrain.The bigger the difference between optimal velocities, the more difficult it is to satisfy the constraints.

Kinematic models of rovers

Table 1. Selected rovers: MER, CRAB and RCL-E.

Breadboard	Schematic view	Kinematic model
MER by NASA (rocker-bogie type)		
		
CRAB by ASL (symmetric structure based on four parallel bogies)		
		
RCL-E by RCL (three parallel bogies, no differential mechanism)		
		

Metrics

i)Difference between input and optimal velocities: Δvel_{opt}

$$\Delta vel_{opt} = \sum_{i=1}^{n} |\vartheta_{ref} - \vartheta_{opt_i}| \quad with \quad i \neq ref$$

$$\begin{aligned} \text{where} \quad \vartheta_{ref} &= \text{velocity of reference wheel,} \\ \vartheta_{opt_i} &= \text{optimal velocity of wheel } i, \\ n &= \text{number of wheels.} \end{aligned}$$

ii) Slip

Slip is defined as the difference between the displacement of a wheel measured at the wheel center point and the displacement derived from wheel rotation measurement with encoders.

Simulation results

Tests 1-3 show that there is a significant difference between the performance of MER (15-27 m/s) and the other rovers (10-13 m/s), CRAB and RCL-E. This means that, if a constant speed control was used on the rovers, the error would be much bigger on MER or, in other words, MER has a higher need to adapt the wheel velocities in order to satisfy the kinematic constraints and reduce slip. The performance is influenced by the selection of the reference wheel for all rovers, whereas the results for MER show the biggest influence, i.e., the performance varies by almost 50%. It is interesting that the performance of CRAB reflects the symmetrical suspension with the same results for front and rear wheel. The results from tests 1-3 are confirmed by tests 7-9 on uneven terrain.

Link to the paper

https://drive.google.com/open?id=1-HShnPeNCBrMwHbygRxv3M5DhKVMtS-F

Table 2. Simulation results for metric Δvel_{opt}.

Rover	Ref. wheel	Test	$\sum(\Delta vel_{opt})$ [m/s]	Test	$\sum(\Delta vel_{opt})$ [m/s]
MER	1	1	27.87	7	93.71
CRAB			12.17		37.53
RCL-E			12.72		35.69
MER	2	2	15.87	8	55.46
CRAB			10.00		28.00
RCL-E			11.12		29.96
MER	3	3	17.25	9	55.20
CRAB			12.02		37.87
RCL-E			11.69		33.70
Terrain type		Truncated pyramid		Uneven terrain 24m	

Table 3. Simulation results for metric slip.

Rover	Ref. wheel	Test	Slip (control type) const.speed	model-based	Test	Slip (control type) const.speed	model-based
MER	1	1/4	1.12	0.61	7/10	4.19	2.46
CRAB			0.64	0.24		1.89	1.00
RCL-E			0.69	0.21		1.97	0.94
MER	2	2/5	1.12	0.49	8/11	4.19	1.99
CRAB			0.64	0.20		1.89	0.85
RCL-E			0.69	0.22		1.97	1.23
MER	3	3/6	1.12	0.51	9/12	4.19	1.94
CRAB			0.64	0.22		1.89	1.02
RCL-E			0.69	0.22		1.97	0.99
Terrain type		Truncated pyramid			Uneven terrain 24m		

Conclusion

The new metric Δvel_{opt} was introduced with the aim to characterize the suspension systems in terms of compliance with kinematic constraints while moving on uneven terrain. For this, the optimal wheel velocities depending on the rover's state were calculated by means of a kinematic model. Slip was used as a second metric because it occurs if kinematic constraints are violated. A large number of simulations was performed with different settings. The rovers CRAB and RCL-E performed well with respect to both presented metrics while MER's performance was significantly inferior. It was also shown how integration of kinematics in a model-based controller improves performance.

02/06/20

<u>Analysis of Grouser Performance to Develop Guidelines for Design for Planetary Rovers</u>

1. Chevron-shaped grousers can increase tractive efficiency (the ratio of output to input work for the wheel), though only in relatively benign or low slip operations.
2. grousers increase lateral forces during sideslip operations, improving performance on cross-slopes, but decreasing skid-steering efficiency.

Straight grousers

Straight travel test

3. an increase in the number of grousers can reduce the forward soil flow in front of the wheel. Forward soil flow causes an increase of motion resistance on the wheel, and thus decreases net drawbar pull.
4. wheel can generally achieve high tractive efficiency at slip ratio of around 0.1–0.3.
5. the drawbar pull increases with the increase of the number of grousers in all the conditions; however, the rise in drawbar pull reaches a plateau when the wheel has a certain number of grousers

6. The results suggest the grouser spacing equation (7) is valid for different soil materials and different heights of grousers. However, the equation is based on an analysis of straight grousers in simple forward travel.

Sideslip test

7. During sideslip tests, 24 grousers are shown to produce significantly higher drawbar pull than 12 grousers at 20 percent slip, but produce little to no discernable advantage over 12 grousers at 60 percent slip.
8. we also see that drawbar pull decreases with increasing sideslip angle at low slip, but that it is not sensitive to sideslip angle at higher slip
9. the lateral force increases along with the increase of the slip angle and decreases with the increase of the slip ratio.

Chevron grousers

Straight travel test

10. the variance in drawbar pull is largest with straight grousers and decreases with the increase of the chevron angle of grousers.
11. the drawbar pull decreases with the increase of the grouser chevron angles, especially at high slip rate and hence straight grousers are better in this regard.
12. negatively oriented grousers tend to gain higher drawbar pull.Grousers with steeper orientation induce higher sinkage,and positive orientations result more sinkage than negative ones, especially at high slip conditions
13. This higher sinkage makes higher motion resistance for chevron grousers, thus lower drawbar pull
14. Steeper chevron grousers gain higher tractive efficiency at low slip conditions ($s < 0.2$)
15. On the other hand, at higher slip, however, straight grousers gain higher tractive efficiency than chevron grousers because of their high drawbar pull compared to chevron grousers.

Sideslip test

16. the drawbar pull decreases with increasing slip angle at low slip conditions, but at the high slip condition, the drawbar pull does not change largely.
17. The differences of drawbar pull are not large for different grouser orientations compared to the influence of slip ratio and slip angle
18. The lateral force increases with the increase of the slip angle and decreases with the increase of the slip ratio. The orientation of grousers has more influence on the lateral force than the drawbar pull.
19. At the slip ratio of s = 0, the chevron grousers gain higher lateral force than straight grousers, especially at large slip angles. However, when the slip ratio increases, the lateral force of straight grousers becomes larger than that of chevron grousers

Conclusion

20. explicit steering is a good choice for wheels with grousers.
21. The dependency on low slip makes chevrons particularly suitable for flat benign terrains where efficiency is of paramount importance.
22. For steep slopes or other challenging terrains, straight grousers may still be preferable in the tradeoff of peak performance for average efficiency

Reference Link

https://drive.google.com/file/d/1awjkNqhDAZaBLuCJzhmcSk8fnZjfrBrC/view?usp=sharing

Comparison of Suspension Systems and Chassis of Selected Mars Rovers Analogs with a Focus on Introduced Improvement

Introduction

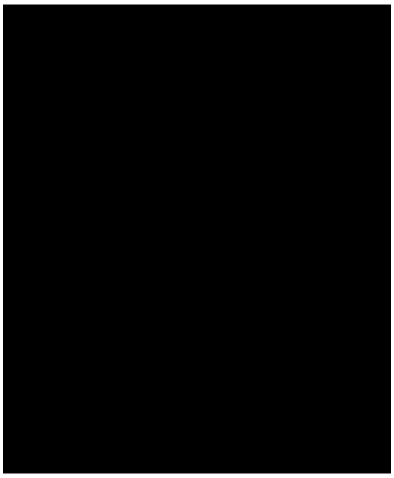
Authors talked about the need of consistent improvement in space exploration and the need of new generation mars rovers to assist humans on mars.

Mars rovers from Bialystok University of Technology

1. **Magma**

Its chassis is made of plastic, each of the four wheels is driven independently. Finished third in URC 2010.

2. **Magma 2**



Successor of the Magma was Magma 2 (fig. 4). It has increased number of wheels from four to six. The structure is made of high density polycarbonate what resulted in the robot’s very low weight. In an University Rover Challenge competition in 2011 Magma 2 took first place.

3. **Hyperion**

The suspension system is based on a Rocker-Bogie system.The frame is made of aluminum sheet and profiles.In a University Rover Challenge 2013 competition, Hyperion took first place winning with a record number of points 493 to 500 possible.

4. **Hyperion 2**

   More compact and slightly smaller. To reduce weight more plastics were applied. The frame is made of aluminum profiles (fig. 8). They used welded aluminium frame instead of Monocoque.In 2014, at URC competition Hyperion 2 took first place.

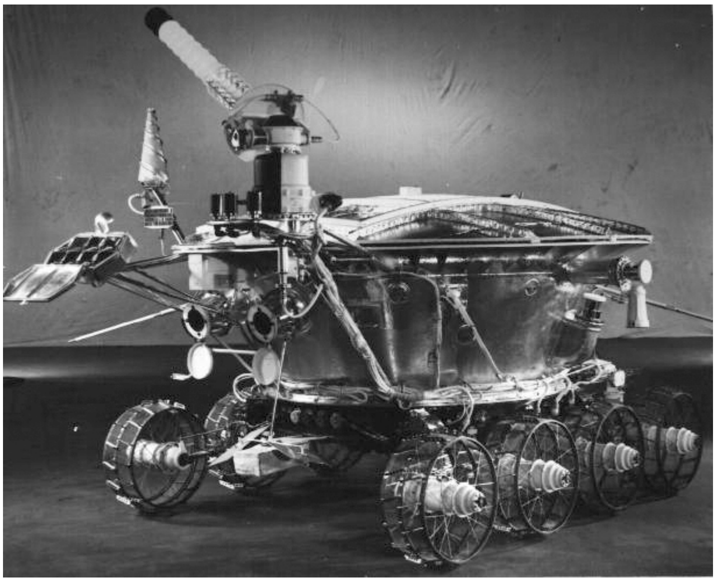
5. **#next**

   #next was much larger. The electronic components, in contrast to predecessors, were located below the frame, and not on it. Additionally, modules were located on the drawer enabling quick and easy service. The great advantage of the construction was very high ground clearance.

In summary section of the paper authors highlighted that in competition like URC materials need not to be in accordance with the martian weather. But what is most important is that the concept of suspension and chassis rover.

Rover Suspension Systems

1. Independent Spring Suspension



This type of suspension system was notably used on the two russian lunar rovers,Lunokhods. It consisted of eight wheels.The Lunokhods were the size of a compact car with a wheel base of 1.7m and a track of 1.6m. The eight wheel suspension was designed to allow the vehicle to traverse obstacles 40cm high. The 51cm diameter wheels were independently powered with a multi-speed motor. treads. In order to reduce the complexity of the drivetrain the rover used differential or “skid” steering to change direction.

2. Articulated Body Suspension

The articulated body rover has multiple body segments with a pair of drive wheels

under each. The center axle is a passive hinge to allow all six wheels contact with the

ground on uneven terrain. Usually rovers with this suspension have low ground clearance.The rovers change direction by steering the front and rear cabs with respect to

the center cab. Both wheels under each cab remain parallel at all times. This is

typically called wagon-wheel steering.During sharp turns the wagon-wheel suspension becomes unstable. Due to heavy equipments situated at lower side, the center of gravity is very low.

3.Rocker bogie suspension

1. All rovers that have landed on mars are 6 wheeled rocker bogie systems.
2. The rocker bogie suspension can surmount obstacles head on that are larger than a wheel diameter because it uses an extra set of wheels to provide more forward thrust.
3. Typically a four wheeled rover can not climb obstacles larger than a wheel radius because the rear wheels do not have enough traction.

4. The extra wheels also reduce the normal force on each wheel by about 1/6 the weight of the rover.
5. Each side of the suspension has two links, a main rocker and a forward bogie.
6. Making all wheels steerable will increase the movement flexibility of the rover and will help in performing crabbing maneuvers.

Link to the thesis-
https://drive.google.com/file/d/13xvY-seO-hjo9-VsiFmExOLFUFZXL93m/view?usp=sharing

7.

28/05/20

Wheels

Causes of tears in curiosity

The two rear wheels have scratches and dents but no holes that I can see anywhere (except for the odometry markings).On middle and front wheels, most (but not all) of the big holes are in the center section of the wheel — that is, they are on the "crown."

1. The wheels were designed to bend quite a lot, and return to their original shape. But the repeated bending and straightening is fatiguing the skin, causing it to fracture in a brittle way.

2. The stresses from metal fatigue are highest near the tips of the chevron features, and indeed a lot of tears seem to initiate close to the chevron features.

Causes of punctures in curiosity

1. Immobile pointy rocks strongly embedded to rock bed
2. If we look at the design of the rocker-bogie system, we can see that the arms that support the middle and front wheels are angled downward. If a front or middle wheel hangs up on a rock and the rest of the rover keeps driving, the arm is exerting a downward force on the wheel. But the rear wheel doesn't experience that same downward force — it's dragged behind the arm, like a wheeled suitcase.

Observations and Recommendations

05/06/2020

1. I observed that most of the top teams in SAR videos were using inflatable tyres. This further suggests that we don’t need to worry about using the materials which would be capable of withstanding the martian environment.
2. After reading about the grousers I came to the conclusion that chevron have their own advantages and straight grousers have their own. So I recommend making the hybrid of two. It would be wavy like structure.