AUTONOMOUS ACTIVE TYPE SUSPENSION

The drive system comprises a 6-wheeled **autonomous custom-designed multi-link active suspension based on a five-bar mechanism** with **tires constituting of interwoven helixes made up of shape memory alloy**. This has provided us with high mobility, great adaptability to the terrain and an improved chassis stability. The use of an active suspension helps eliminate a differential or a strut. Four links (two on each side of the rover) are actuated by **worm & worm wheel geared motors**.

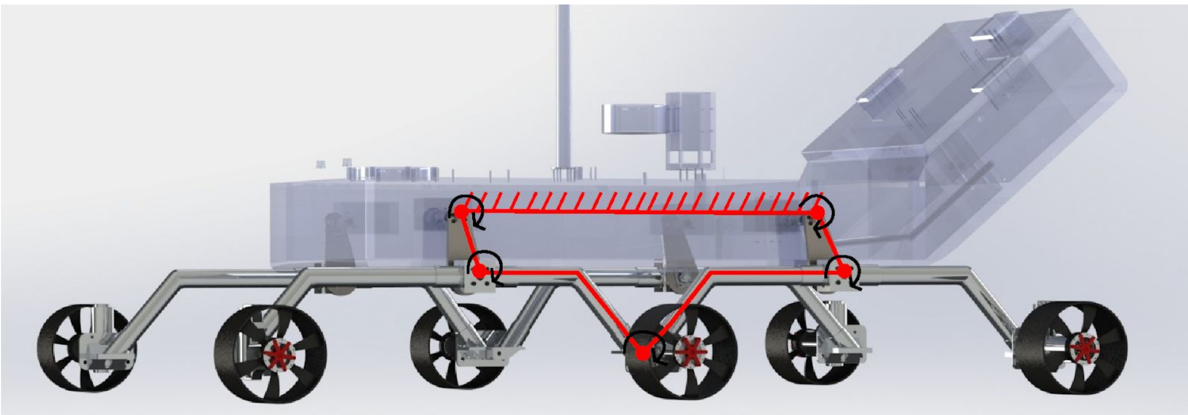


Fig 4 -Schematic of the active suspension

WHEELS

The drive train consists of brushed DC motors combined with 4 stage planetary gearheads. The combination offers sufficient torque to traverse over Martian terrain.Considering the 15 sol mission time, the drivetrain enables the rover to traverse from one end of a 20km radius site to the other in approximately a day with a maximum speed of **0.4 m/s**.
Each wheel is individually powered. The outermost wheels along the wheelbase are equipped with a steering mechanism that enables the rover to efficiently steer and make zero-radius turns.

Fig 5 -Wheel motor assembly

The wheel is equipped with a **full float axle design** to ensure minimum load on the motor shaft. It is made of Aluminium (grade 7075 T7351) with a Type III black anodised finish.

The tires are made of **Nitinol** (Nickel-Titanium alloy) mesh with a helical interlinked weave that exhibit properties of superelasticity and shape memory. The material, also called as Shape memory alloy, elastically deforms under stress and springs back to its original shape upon removal of load due its characteristic at an atomic level. The tires are capable of deforming completely until the surface of the drum without undergoing any plastic deformation. This enables the rover to have adaptability to terrain (complementing the 5 bar suspension) without any loss of traction.

Case (i) - 6 WHEELED	Design - 1	Design - 2	Design - 3	Design - 4	Design - 5 (final)	UNITS / CONDNS.
Gross vehicle weight (**GVW**)	392	573.5	758.5	577	1665	N
Number of wheels (**n**)	6	6	6943.5	6	6	wheels
Reality check	176.4	5.495922558	7.268800802	5.529463497	749.25	Nm
Weight on each drive wheel (**Ww**)	65.33333333	95.58333333	0.109238856	96.16666667	277.5	N
Radius of wheel/tire (**Rw**):	0.3	0.3	0.3	0.3	0.3	m
Desired top speed (**Vmax**):	0.4	0.4	0.4	0.4	0.4	m/s
Desired acceleration time (**ta**):	10	10	10	10	10	s
Maximum incline angle (**α**):	60	60	60	60	60	degrees
Coefficient of rolling friction (**Crr**) - heavy sand	0.4	0.4	0.4	0.4	0.4	sandy dirt
μ	1.5	1.5	1.5	1.5	1.5	μ
RR [N] = **GVW** [N] x **Crr**	156.8	229.4	303.4	230.8	666	N
GR [N] = **GVW** [N] x sin(**α**)	339.3778571	496.5132679	656.6788383	499.5434274	1441.490133	N
FA [N] = **GVW** [N] x **Vmax** [m/s] / (3.7 [m/s2] x **ta** [s])	4.237837838	6.2	8.2	6.237837838	18	N
TTE [N] = **RR** [N] + **GR** [N] + **FA** [N]	500.4156949	732.1132679	968.2788383	736.5812652	2125.490133	N
Tw [Nm] = **TTE** [N] x **Rw** [m] x **RF**	172.6434147	252.5790774	334.0561992	254.1205365	733.2940958	Nm
MTT = **Ww** [N] x **μ** x **Rw** [m]	29.4	43.0125	0.049157485	43.275	124.875	Nm
MTT x **n**	176.4	258.075	341.325	259.65	749.25	should be more than Tw
Required torque per drive wheel	28.77390246	42.09651291	0.048110636	42.35342275	122.2156826	Nm
Torque in kg-cm	293.6112496	429.5562542	0.490924854	432.1777832	1247.098802	kg-cm
RPM required	12.7388535	12.7388535	12.7388535	12.7388535	12.7388535	RPM

Fig 6 - Wheel Motor Torque Calculations

SUSPENSION

The suspension is based on a five bar mechanism which provides two degrees of freedom. This increases the terrain adaptability and chassis stability by a great extent when compared to the other rover suspensions. The suspension is majorly manufactured with **Aluminium 7075 T7351**. The bogies are aluminium tubes of a circular cross-section which is bent to shape using CNC bending. Further, the bogie is fastened to the respective connectors by the help of rivets. The control link is made of Ti 6Al - 4V or grade 5 Titanium plate and is laser cut to shape.

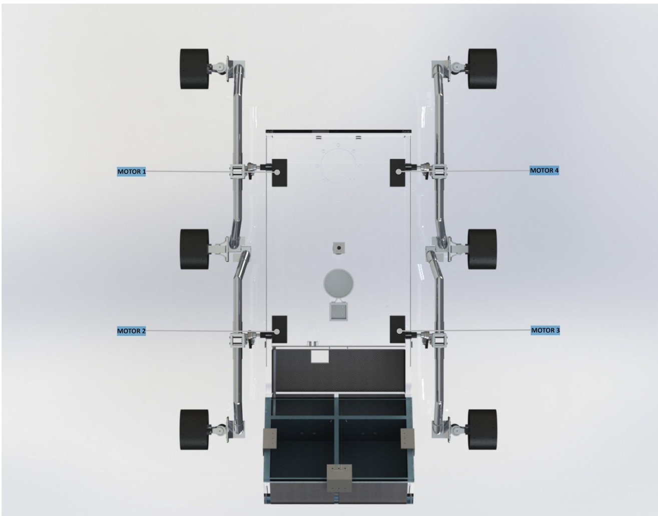
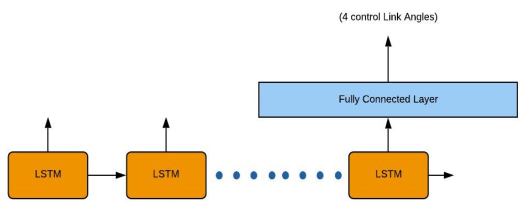


Fig 7-Top view of the drive system showing the 4 motors

The materials are chosen keeping in mind the harsh temperature variation on the martian land. The suspension geometry was finalised after multiple iterations of kinematic and dynamic motion simulation. Keeping in mind the martian terrain, the rover can traverse 650mm high vertical obstacles, a slope of 65 degrees incline and a vertical ditch of height 2000mm. Further, with the aid of artificial intelligence, the chassis is kept horizontal at most times keeping the other sensitive components on board the rover safe from sudden shocks and jerks due to the rough terrain.



Given the recent advancements in the field of deep learning and its applications in the field of robotics, an LSTM has been trained, tested and implemented for the control of our active suspension. LSTM (Long Short-Term Memory Network) is a modification of the Recurrent Neural Network model that is used for the purpose of time series analysis. LSTMs carry long term dependencies over time. As the current as well as past data of traversal over obstacles can be used to forecast how the control link angles must change, we thus picked an LSTM model to predict the control link angles.

The architecture of the network is given below:

Fig 8 -LSTM time series depiction

Training process:

1.Preparation of the dataset:

For the training of our LSTM model,first the input features were decided. The input features chosen were normal reaction forces on the wheels and the centre of the rover, distance from an obstacle,velocity of the rover and height of the obstacle,which is negative if its a ditch.The height/depth of an obstacle is split into two features, i.e, the height of the obstacle on the left of the rovers centre and on the right.This is done so that the model learns to move the left and right side of the suspension independently.Also the height/depth for an obstacle is floored to 0 until the rover is 10cm away from the obstacle since, because prior to this the suspension doesn't have to undergo any change and hence the model learns to do nothing until actually required.The output for the model are the control link angles.

5000 data points were extracted for the aforementioned features by running a dynamic simulation of the rover on martian-like terrain on SolidWorks.

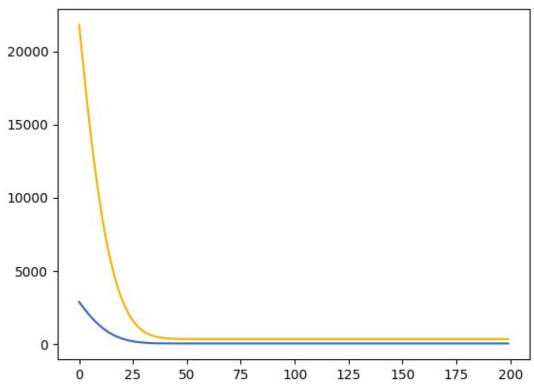


Fig 9 . Plot of MSE vs No. of Epochs

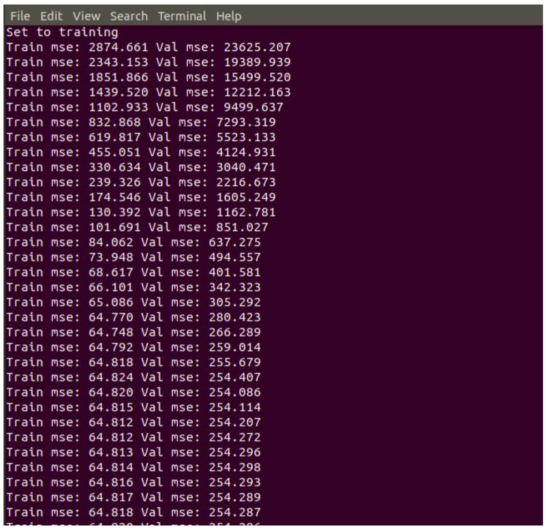


Fig 10 . Training of the model

2.Training and tuning:

Prior to training, a sliding window was used on the dataset to generate sequences of 42 consecutive time steps. Then the newly generated grouped dataset is split into train,validation and test set using a ratio split of 70-10-20.

Since the goal of the model is used to predict the control link angles at the next time-steps given the inputs of the 42 previous time-steps,the model has been trained accordingly. Hence the loss function is the mean squared error computed from the output produced from the last time step in a sequence and the label for the next time step.

The hyperparameters such as learning rate ,number of epochs,number of hidden units and hidden layers were tuned to minimise the mse of the validation set.

3.Results:

The LSTM model produced decent results which can be deployed on a rover and easily improved as more training data is collected during actual traversal on Mars. The metric chosen to represent the results is root mean square error as we are aiming to regress the control link angles. The model achieved an RMSE of 13°. The error while still a bit significant due to the low training data used can be overcome by the structure of the suspension and due to the presence of a software threshold of 30°, above which the motor will actuate the control links of the suspension to overcome any obstacle.

Deployment:

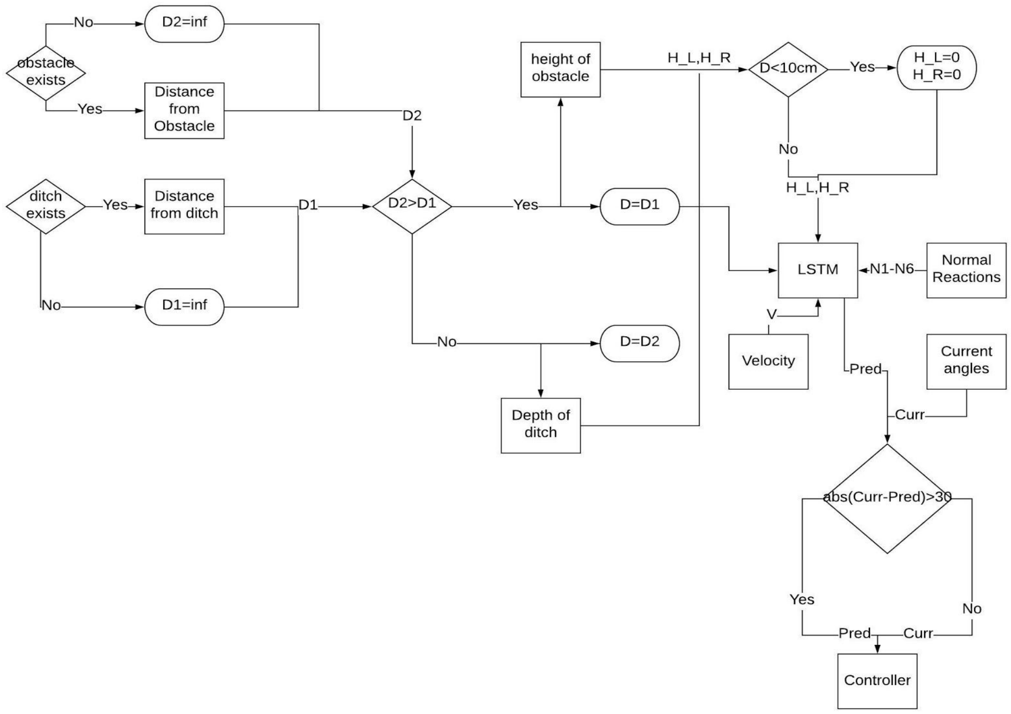


Fig 11 :Deployment flowchart for LSTM

As seen in Fig 11, the model only takes obstacles/ditches that are closer than 10cm into consideration, so as to only react when necessary. Obstacle/ditch information such as distance from it or height/depth is given from the processed feed of the stereo cam. The normal reactions are given by force sensors appropriately placed on the wheels. The controller only makes a change to the suspension if the change is greater than a fixed threshold.