Drive System

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 helices 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 control links (two on each side of the rover) are actuated by **worm & worm wheel geared motors**.

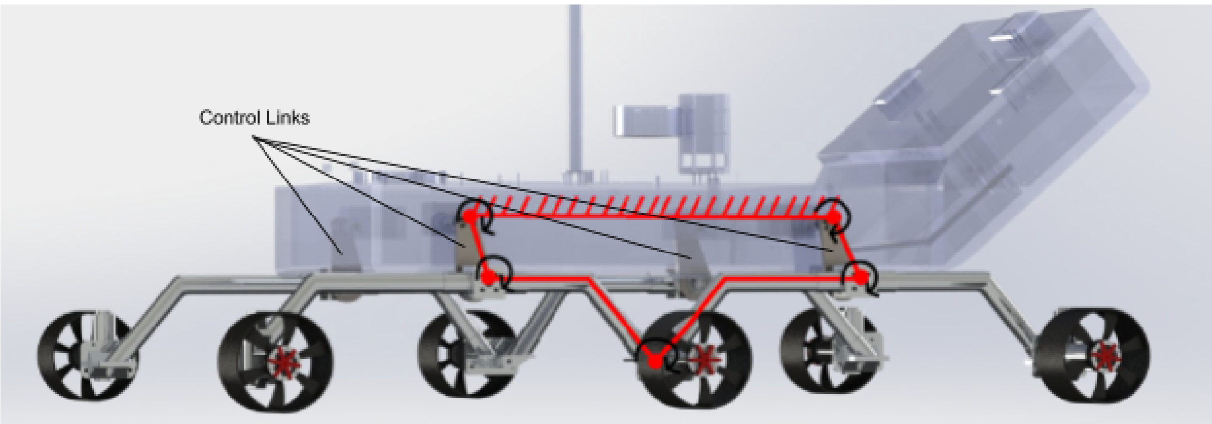


Fig 4 - Schematic of the active suspension

Wheels

The drive train consists of brushed DC motors combined with 4 stage planetary gearheads. The combination offers torque up to **1788 Nm** to traverse over Martian terrain. Considering the 15 sol mission time, the drivetrain enables the rover to traverse from one end of a 20 km radius site to the other in approximately one sol 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.

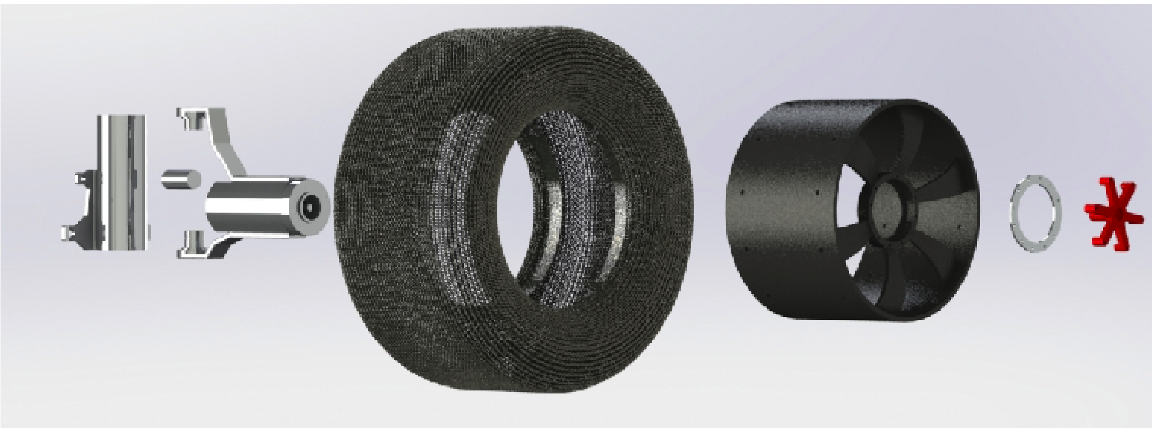


Fig 5 - Wheel motor assembly

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 anodized finish.

The tires are made of **Nitinol** (Nickel-Titanium alloy) mesh with a helical interlinked weave that exhibits properties of superelasticity and shape memory. The material, also called shape memory alloy, elastically deforms under stress and springs back to its original shape upon removal of load due to 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 the adaptability to terrain (complementing the suspension) without any loss of traction. Refer to **[Appendix A: 1]** for the detailed 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**[Appendix A:4]**. The suspension is majorly manufactured with **Aluminium 7075 T7351[Appendix A:5]**. The bogies are aluminium tubes of a circular cross-section which are bent to shape using CNC bending. Further, the bogies are fastened to their respective connectors by the help of rivets. The control link is made of **Ti 6Al - 4V** and is laser cut to shape.

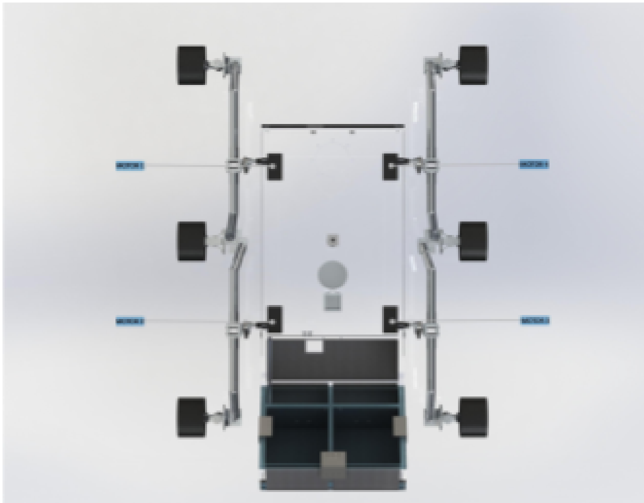


Fig 6 - Top view of the drive system showing the 4 motors

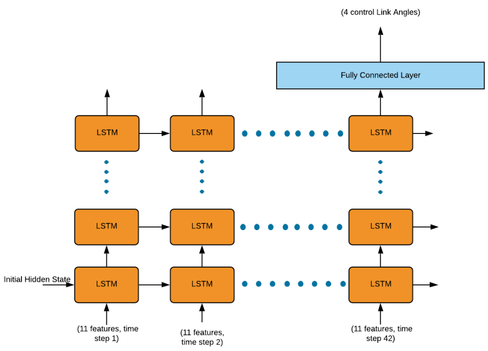


Fig 7. - LSTM model used for Regression

The materials are chosen keeping in mind the harsh temperature variation on the Martian land. The suspension geometry was finalized after multiple iterations of **kinematic and dynamic motion simulation**. Keeping in mind the Martian terrain, the rover can traverse **650 mm high vertical obstacles**, a **slope of 65 degrees incline** and a **vertical ditch of height 2000 mm**. Further, with the aid of artificial intelligence, the chassis is kept horizontal at most times keeping the other sensitive components onboard 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)**[Appendix A: 9]** is a modification of the Recurrent Neural Network model that is used for 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 in Fig 7.

<u>Training process:</u>

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 it's 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 rover's 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 10 cm 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**.

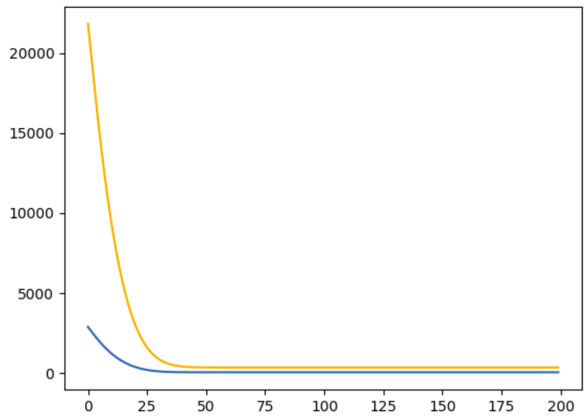
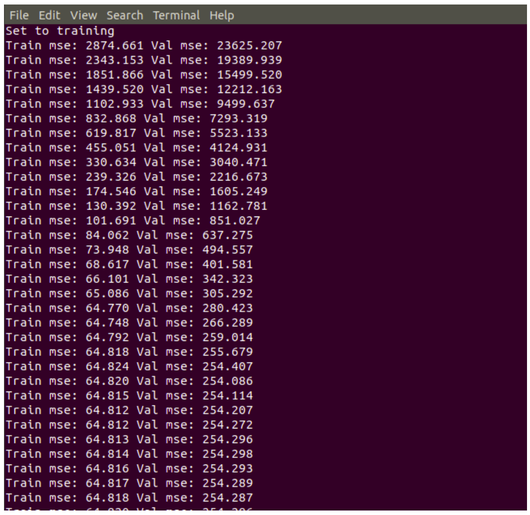


Fig 8 - Plot of MSE vs No. of Epochs for Train and Validation Sets



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File  Edit  View  Search  Terminal  Help
Set to training
Train mse: 2874.661 Val mse: 23625.207
Train mse: 2343.153 Val mse: 19389.939
Train mse: 1851.866 Val mse: 15499.520
Train mse: 1439.520 Val mse: 12212.163
Train mse: 1102.933 Val mse: 9499.637
Train mse: 832.868 Val mse: 7293.319
Train mse: 619.817 Val mse: 5523.133
Train mse: 455.051 Val mse: 4124.931
Train mse: 330.634 Val mse: 3040.471
Train mse: 239.326 Val mse: 2216.673
Train mse: 174.546 Val mse: 1605.249
Train mse: 130.392 Val mse: 1162.781
Train mse: 101.691 Val mse: 851.027
Train mse: 84.062 Val mse: 637.275
Train mse: 73.948 Val mse: 494.557
Train mse: 68.617 Val mse: 401.581
Train mse: 66.101 Val mse: 342.323
Train mse: 65.086 Val mse: 305.292
Train mse: 64.770 Val mse: 280.423
Train mse: 64.748 Val mse: 266.289
Train mse: 64.792 Val mse: 259.014
Train mse: 64.818 Val mse: 255.679
Train mse: 64.824 Val mse: 254.407
Train mse: 64.820 Val mse: 254.086
Train mse: 64.815 Val mse: 254.114
Train mse: 64.812 Val mse: 254.207
Train mse: 64.812 Val mse: 254.272
Train mse: 64.813 Val mse: 254.296
Train mse: 64.814 Val mse: 254.298
Train mse: 64.816 Val mse: 254.293
Train mse: 64.817 Val mse: 254.289
Train mse: 64.818 Val mse: 254.287
```

Fig 9 - 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 minimize 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:

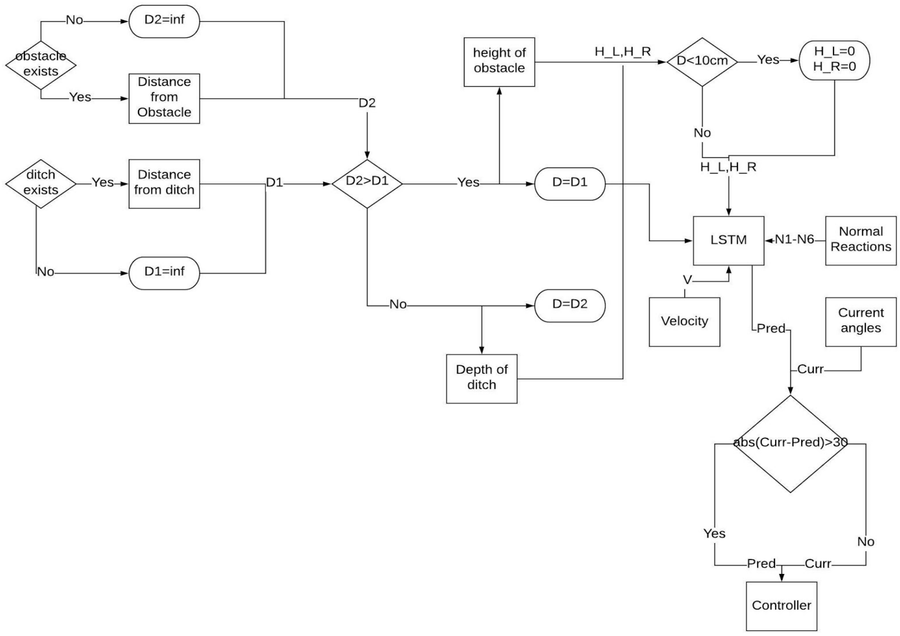

Fig 10 - Deployment flowchart for LSTM

As seen in Fig 11, the model only takes obstacles/ditches that are closer than 10 cm into consideration, 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.

Chassis

The rover's body or the **Chassis** is a strong **monocoque** that hosts and protects the rover computer, electronics, solar panel and the science module of the rover. Composite Materials are used owing to their high strength to weight ratio, infinite fatigue cycles, high performance in extreme environments like high temperature variations and abrupt pressure changes and its ability to withstand and block radiations.

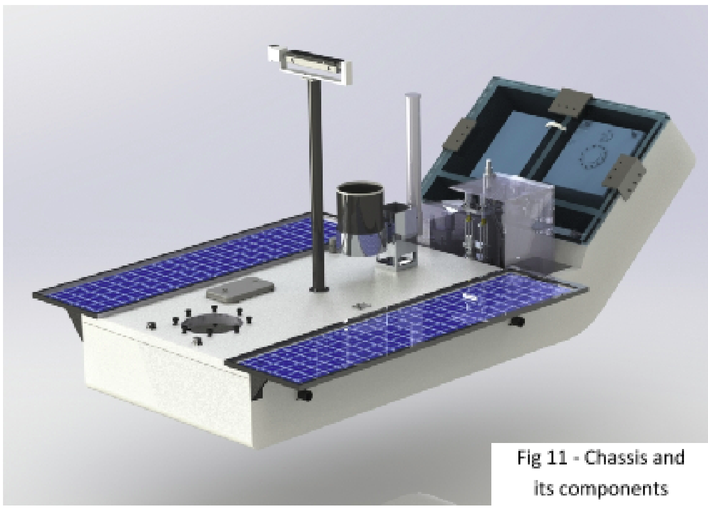

Fig 11 - Chassis and its components

The **Chassis** is made up of a **thermoset prepreg** with space grade **Carbon fibre** as reinforcement and **Cyanate Ester** as the matrix. The reason for choosing cyanate ester based prepreg is that it is toughened to resist microcracking and that offers the advantages of low moisture absorption and negligible volatile emission in space. It has characteristics