Off-Road Roll Control

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Introduction

The Off-Road Roll Control (ORC) project seeks to provide high performance vehicle suspension at budget build prices. Large off road vehicles, like the modern Jeep Wrangler, are top heavy and prone to rolling over in off-balance situations. This problem is exacerbated by disconnected sway bars, lifted suspensions, roll cages, and body armor.

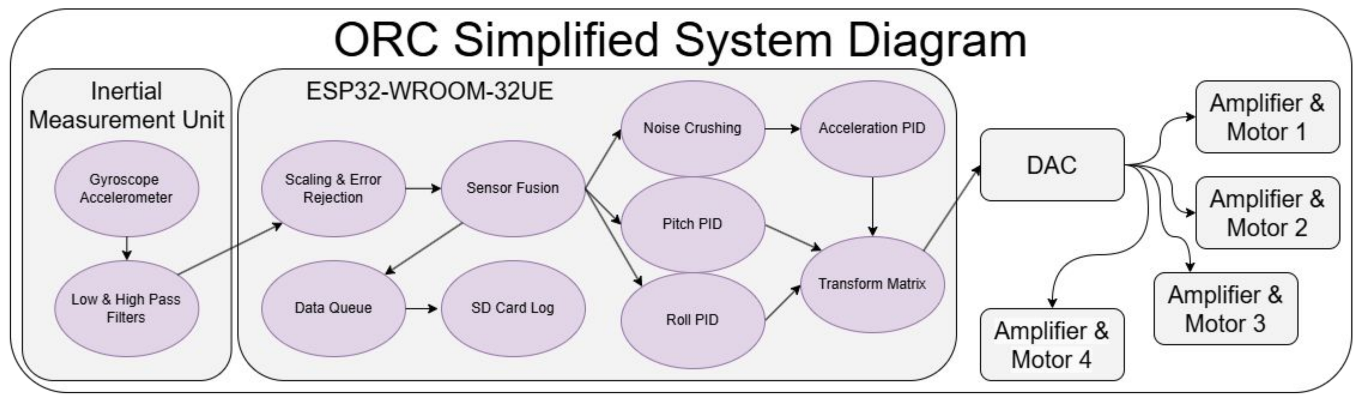
In extreme cases, a vehicle similar to the one described prior could roll over as a result of a low speed emergency maneuver. To help mitigate handling issues like this and to improve passenger comfort overall, an active suspension system is proposed here.

Project Goals

ORC improves passenger comfort by reducing experienced pitch, roll, and vertical jerk relative to a vehicle with no dampers. A real time system contained to only the equipped vehicle is desired. For practical reasons, a 1/10 scale vehicle platform is demonstrated.

Methods

Similar to [1], PID control of actuators is the primary control methodology. The PID controllers respond to vertical acceleration, pitch, and roll. These are measured by an inertial measurement system (IMU), the data from which is combined and filtered. The output of the 3 PIDs are transformed into 4 actuator movements, present at each corner of the vehicle. The outer loop from [1] is excluded as its effect was minimal and increased complexity significantly.



To examine the effects of the control system on vehicle dynamics, the pitch, roll, and vertical acceleration of the vehicle are recorded. From the vertical acceleration data, the jerk (representing the smoothness of the ride) can be derived. This data is recorded while driving over bumpy terrain, off camber, and through tight corners.

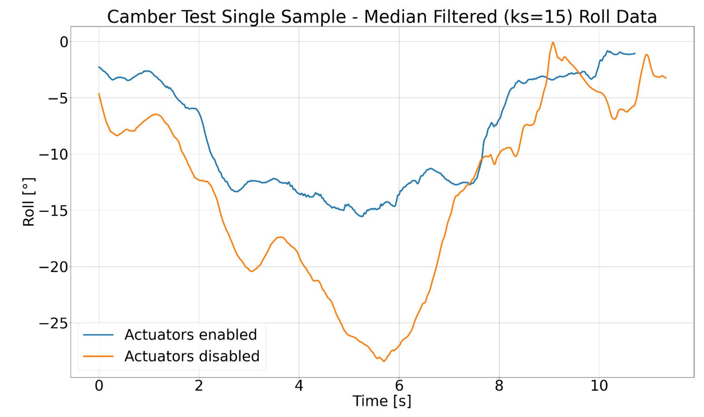
The same terrain (pictured below) is used for testing with actuators enabled, and disabled. Each terrain is driven with a constant speed and minor steering inputs to keep the vehicle on track. Where possible, 20+ test runs were conducted for each actuator status.

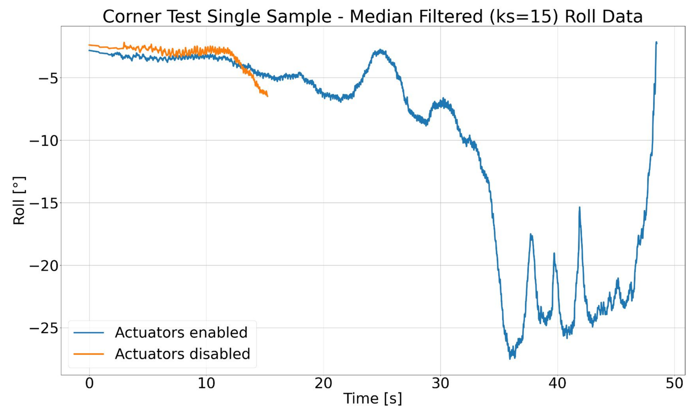
Figures and Results

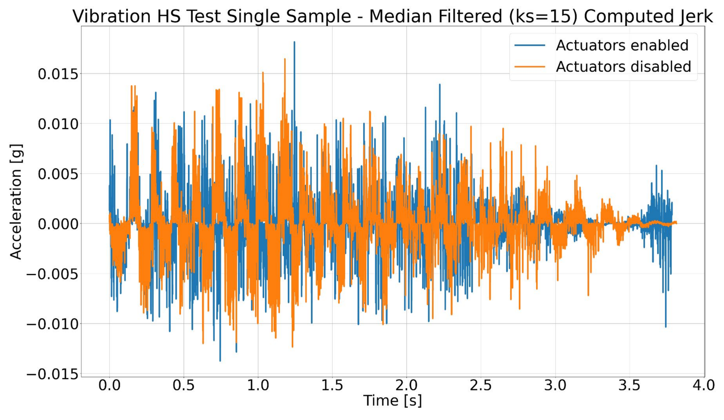
To implement actuators on a scale prototype, several solutions were explored, but ultimately a gear motor with a lever arm was chosen. This solution allowed the suspension to move freely, without too much damping coming from the motors themselves. These gear motors are mounted to the frame of an 1/10 scale RC rock crawler. Linkages connect the lever arm to the axle on both the driver and passenger side of the vehicles. By varying the magnitude and polarity of the current sent to these motors, a variable force between the axle and frame can be realized.

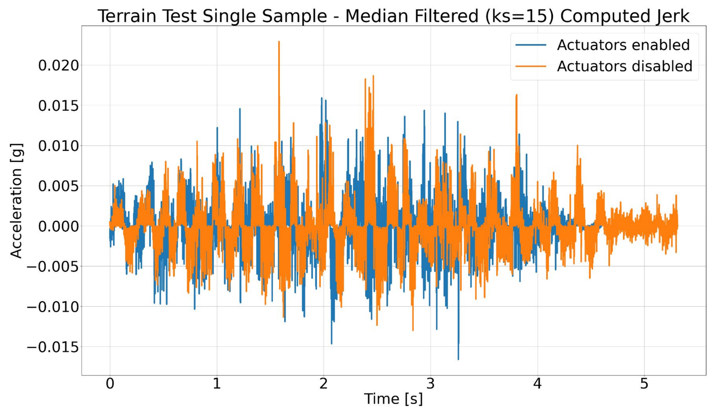
This variable current comes from the custom motor driver boards, which take a ±2.5V signal from the main board's DAC and converts it to a ±16V signal used to drive the motors up to about 2A.

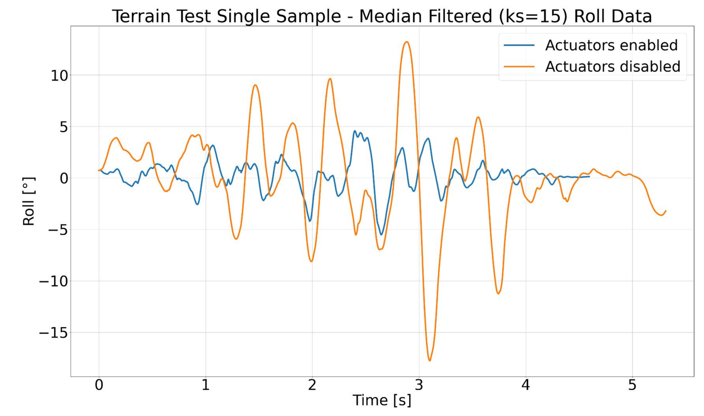
The collected data was processed with a Python script that applied a median filter to knock out random peak readings, plotted a single run's data, and performed a one-sided T-test, discussed in the next section. Selected plots are displayed below.

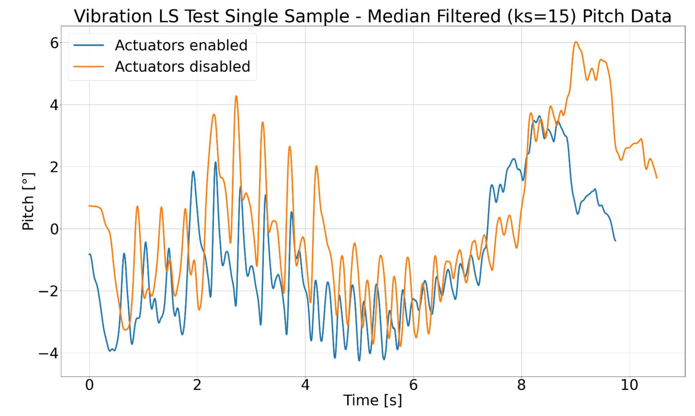












All of the plots and test results are fairly representative of the actual vehicle dynamics except those from the corner test. This test involved driving at increasing speed with a fixed steering input until the vehicles max speed was reached or the vehicle rolled. The induced centrifugal force confused the sensor fusion algorithm, causing it to misinterpret the direction of gravity and thus the euler angles of the system. To combat this, the number of revolutions completed by the vehicle were counted, where the vehicle with the actuators enabled completed 30.9 rotations on average compared to the actuators disabled completing an average of 5.5.

Conclusion

The ORC system's ability to reduce vehicle roll and jerk is mixed. In almost every case the roll of the vehicle was statistically significantly reduced. In all but one case the experienced jerk was not shown to be significantly less when the actuators were enabled. This is not to say the vehicle performed worse, but the difference between the groups was not large enough to be decisive.

A two sample one sided t-test was used to show statistically significant improvement in ride quality within a 5% confidence interval (CI). The RMS, minimum, and maximum value of each test run was put in one of two data sets (actuators enabled/disabled). This does assume the data follows a normal distribution.

While not part of the initial testing plan, the number of revolutions completed in the corner test was evaluated. This showed significant improvement in cornering ability with a P value of 0.0166, which is well within the 5% CI.

Overall, ORC was successful in improving ride quality, but it is likely that some performance was still left on the table.

One Sided T Test Statistics For Improved (Absolutely Less) RMS, Minimum, and Maximum Values

P-value\Test	Camber (min direction)	Terrain	Vibration High Speed*	Vibration Low Speed	Corner*
Acceleration RMS	6.27E-20	3.84E-03	1.06E-06	1.10E-09	1.00E+00
Pitch RMS	1.19E-07	1.65E-09	1.65E-01	3.10E-33	9.92E-01
Roll RMS	9.81E-20	2.92E-27	1.54E-02	1.02E-24	9.22E-01
Jerk RMS	1.00E+00	1.00E+00	4.45E-01	1.00E+00	9.89E-01
Acceleration MIN	7.92E-14	9.44E-01	4.42E-05	1.00E+00	7.28E-01
Pitch MIN	6.98E-13	1.15E-05	1.78E-01	4.59E-01	9.69E-01
Roll MIN	2.93E-35	4.83E-21	3.16E-04	5.79E-26	9.65E-01
Jerk MIN	1.00E+00	1.00E+00	9.96E-01	1.00E+00	8.33E-01
Acceleration MAX	9.97E-01	4.26E-01	1.52E-06	1.38E-18	9.89E-01
Pitch MAX	1.00E+00	3.26E-16	9.15E-03	2.53E-27	9.83E-01
Roll MAX	6.18E-01	7.81E-34	3.91E-04	2.40E-12	8.60E-01
Jerk MAX	1.00E+00	9.08E-03	7.33E-01	1.00E+00	8.30E-01

*Only tested 5 samples instead of full 20+

(Gray fill not relevant to particular test, included for completeness) | >5% CI | <5% CI

Were development of this platform to continue, better tuning, or automatic tuning, of the PID controllers could reveal more performance. Other control algorithms such as fuzzy logic or the many others suggested in [3] could be tested. Using a voice coil actuator could also prove to improve ride quality further by decreasing response time.

Acknowledgments

Many thanks are extended to the ECE department faculty, especially Dr. Fon Brown, for their extensive support and excellent guidance.

Special thanks are due to Audrey Roennebeck, without whose support this project would not have been possible.

References

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