Design and Control of Ibex - The Auto-Leveling Robot

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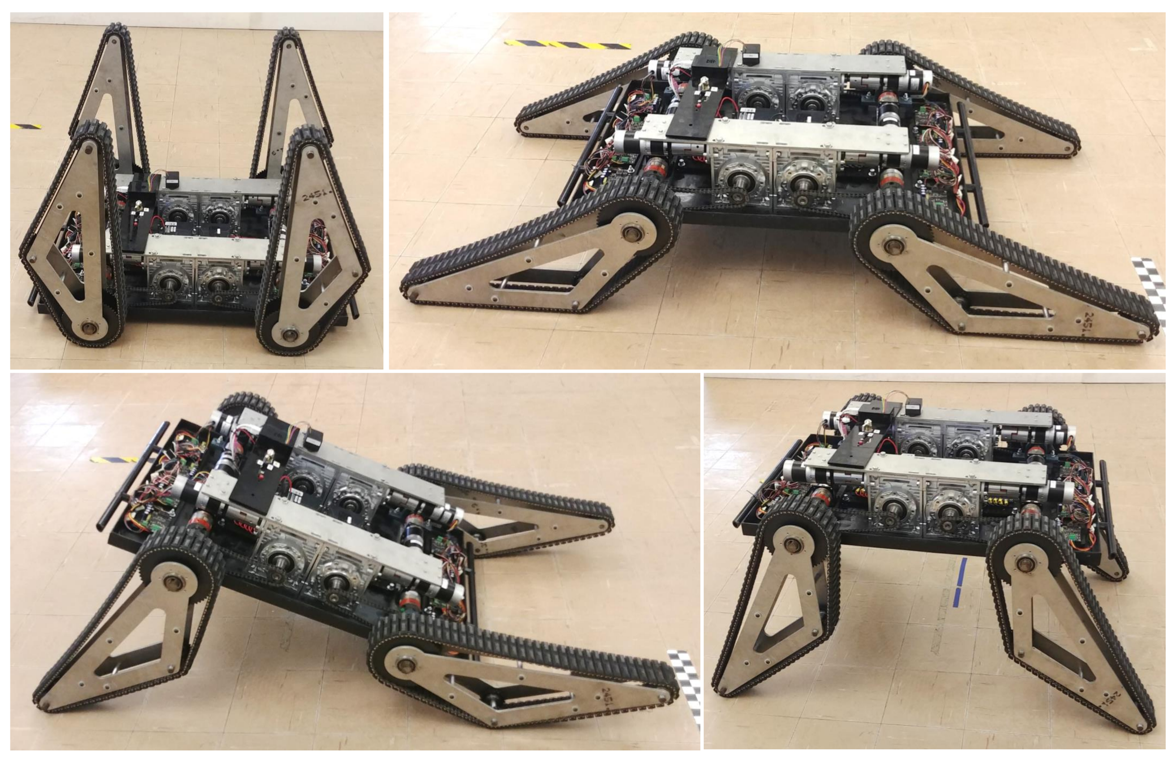
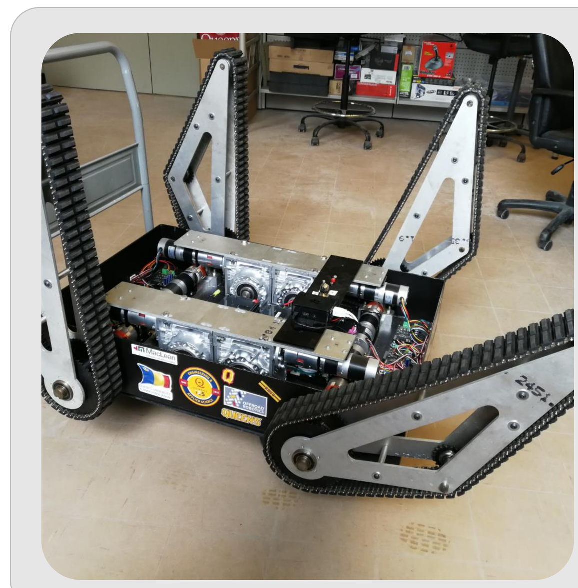
Ibex

Ibex reimagines the mobile robot base as it provides complete control over platform orientation for traversing difficult terrain. Articulating treads allow for creative solutions to terrain challenges while increasing sensitive payload capabilities.

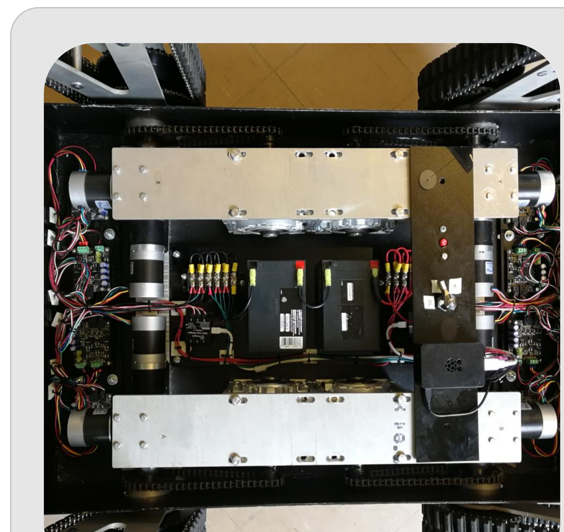


Mechanical Design



- Four independently articulating legs, each with independently driven tracks
- Orientation of tracks control distance to ground surface
- Ground clearance between 5-65 cm

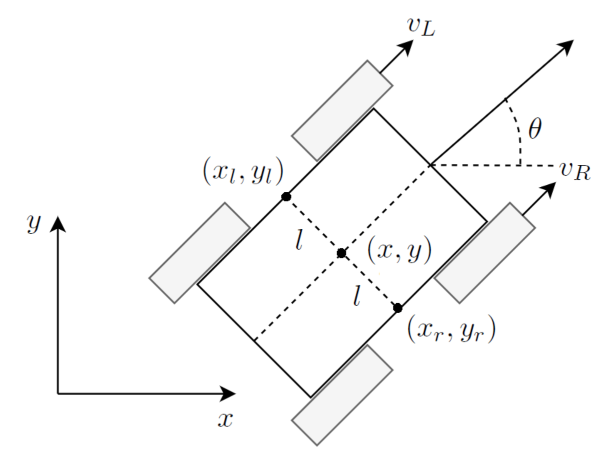
- Skid-steer drive configuration
- Improved handling by independently driving each track
- Triangular shape allows for broad contact patch on ground



- Electric motors heavily geared to provide ample torque for operation
- Steel chassis reinforced for rigidity
- Chassis protects electrical and mechanical hardware

Kinematic Model

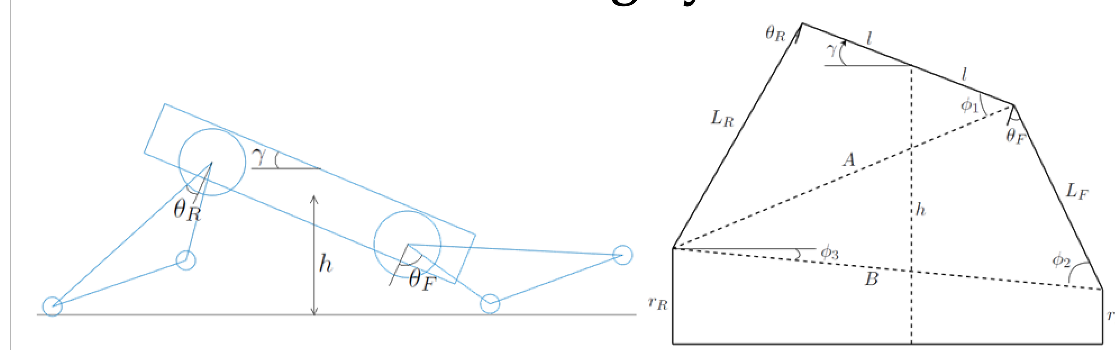
Drive System



$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix} = \begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v\\ \omega\end{bmatrix}$$

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix} = \begin{bmatrix}0.5\cos\theta & 0.5\cos\theta\\ 0.5\sin\theta & 0.5\sin\theta\\ \frac{1}{2l} & -\frac{1}{2l}\end{bmatrix}\begin{bmatrix}v_R\\ v_L\end{bmatrix}$$

Auto-Leveling System



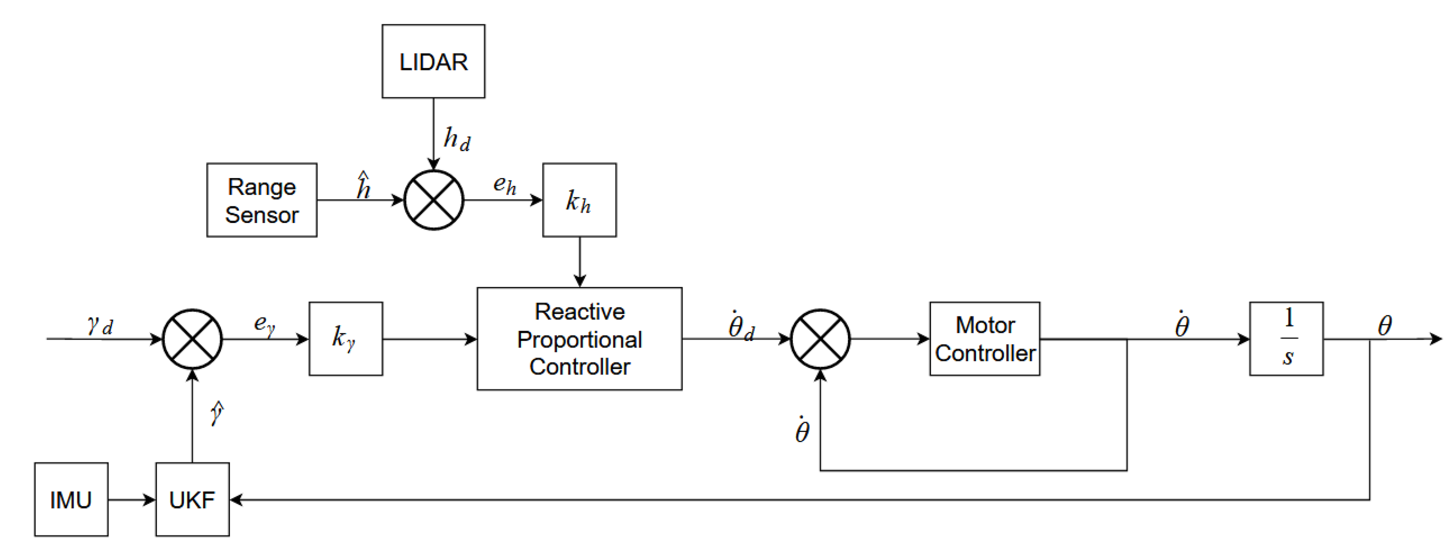
$$\gamma = 90 - \theta_F - \phi_2 - \phi_3$$

$$h = r_F - {L_F}^2 \sin(\phi_2 + \phi_3) + l\cos(\theta_F + \phi_2 + \phi_3)$$

Control System

The initial control system design allows the Ibex to level autonomously in one dimension, the pitch, γ.

Sensor	Use
Inertial Measurement Unit (IMU)	Orientation feedback
Absolute Encoders	Angular position of rotational joints
Lidar	Terrain mapping
Cameras	Terrain mapping
Range Sensors	Height feedback

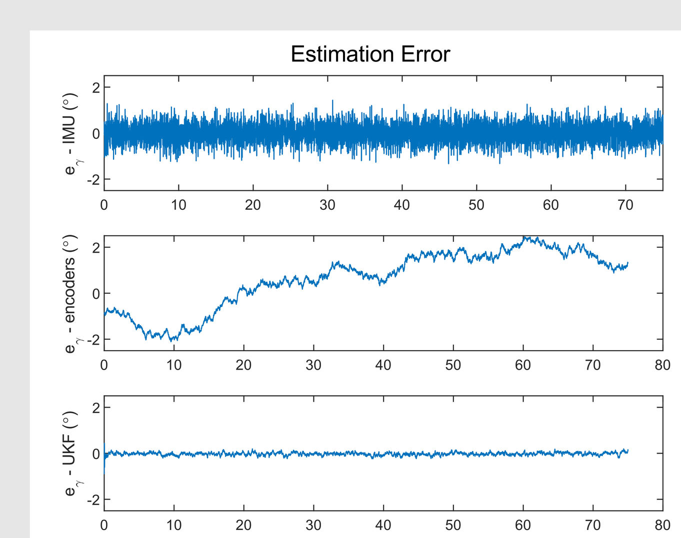


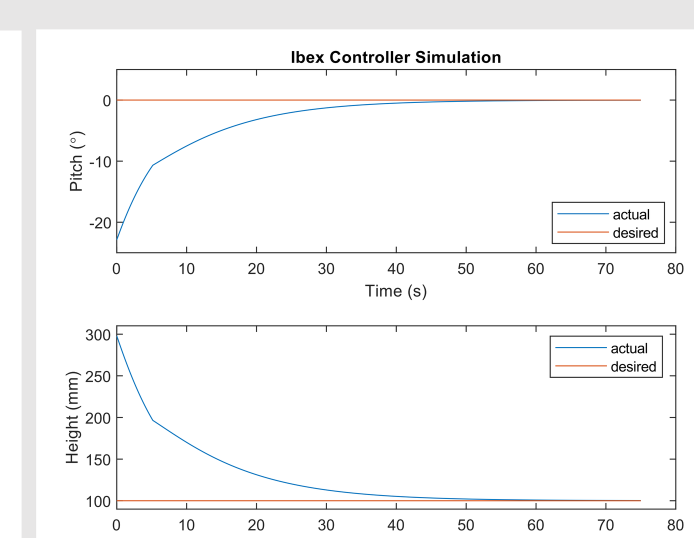
- Reactive proportional controller uses desired height and orientation to output desired motor speeds
- Motor controller determines input motor voltages
- Unscented Kalman Filter (UKF) uses IMU and encoders to filter current orientation

Simulations and Results

Simulations

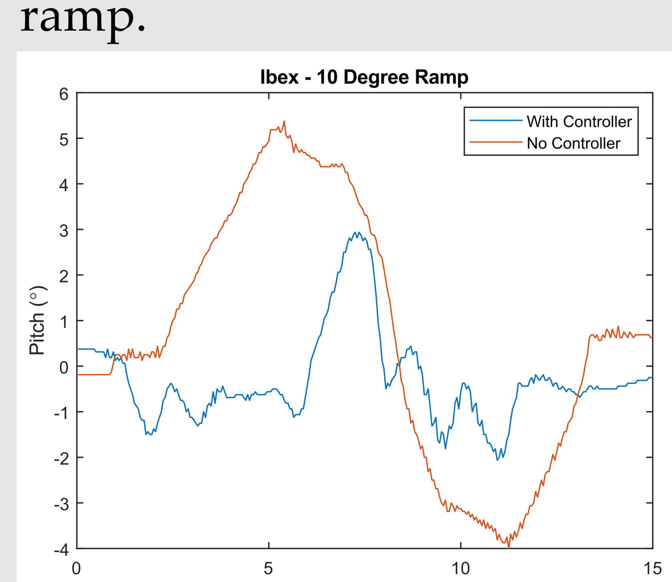
- Simulated in stationary position moving only rotational joints to achieve desired position
- Noise artificially added to sensor readings
- Desired height and pitch are static user inputs
- Motor dynamics not taken into account so simulation times are arbitrary





Implementation on Ibex

Initial tests of pitch controller on the Ibex are able to significantly decrease the change in pitch as it drives over a ramp.

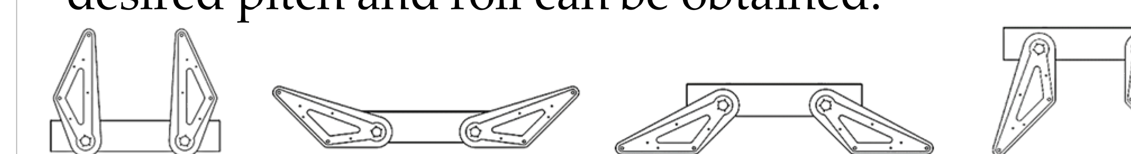


Next Steps:

- Tune gains
- Add roll and height controller
- Range sensors and Lidar for height adjustments
- Implement non-static gains to allow for different load scenarios

Terrain Perception

As a result of the unique articulation of the Ibex, there are often multiple configuration in which a desired pitch and roll can be obtained.



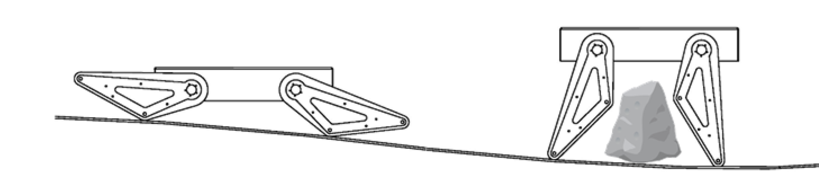
For full control, a desired height must be given to the system along with a desired pitch and roll.

Determining Desired Height

For most applications, the desired pitch and roll of the base will be to maintain a level orientation; however, the desired height is not necessarily a static user input. As the Ibex drives, the terrain and surrounding obstructions can be used to determine what the desired height should be.

Small Obstructions

- If the base is high enough, small obstructions can pass between the treads and under the base.



Steep Terrain

- Move towards more moderate position before upcoming rapid changes

Untraversable Terrain

- Stop Ibex from driving into untraversable terrain

Mapping Methods

- Combine IMU, encoders, Lidar and cameras to map surrounding terrain
- Identify upcoming terrain that requires changes in height

Future Recommendations

Mechanically, improvements to this platform include altering the triangular leg geometry to a shape with a continues curve to provide greater control over ground contact points. It is also desirable to increase the scale of such a platform as this better replicates the final use in mining and forestry industries. As such conversion from electrical to hydraulic actuation should also be considered.

Acknowledgments

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