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Slide-Down Prevention for Wheeled Mobile Robots on Slopes

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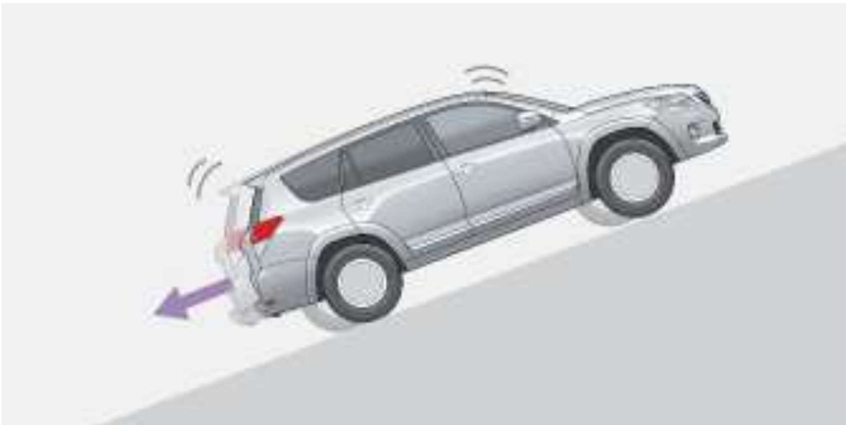
SLIDE-DOWN

- It can be defined as the uncontrolled motion of the whole vehicle on a slope due to gravity and lack of friction.
- It is related with tip-over, vehicle sideslip and traction wheel slippage, but it is a different problem.
- It should be prevented to avoid uncontrolled motion or get the vehicle stuck.



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ROBOT CONFIGURATION

- WHEELED MOBILE ROBOTS: with traction wheels and, optionally, swivel casters.
- SMALL SIZED-ROBOTS: all contact points belong to the same inclined plane.
- MOVEMENT AT LOW SPEEDS: no relevant inertial accelerations, apart from gravity, are present.
- ADHESION FORCE F_{ir}: its direction coincides with the maximum slope. Upwards for traction wheels and negligible for casters.

Lazaro mobile robot

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SLIDE-DOWN MARGINS

- GEOMETRIC APPROACH:

$$I_s^* = 1 - \frac{\sqrt{\sin(\phi)^2 + \cos(\phi)^2 \sin(\alpha)^2}}{\mu \cos(\phi)\cos(\alpha)}$$

where μ is the friction coefficient, and ϕ and α are the pitch and roll angles of the vehicle.

- Values close to zero indicate the maximum slide-down risk, whereas values close to one represent the minimum risk on horizontal plane.

- Valid without caster wheels in contact with the ground.

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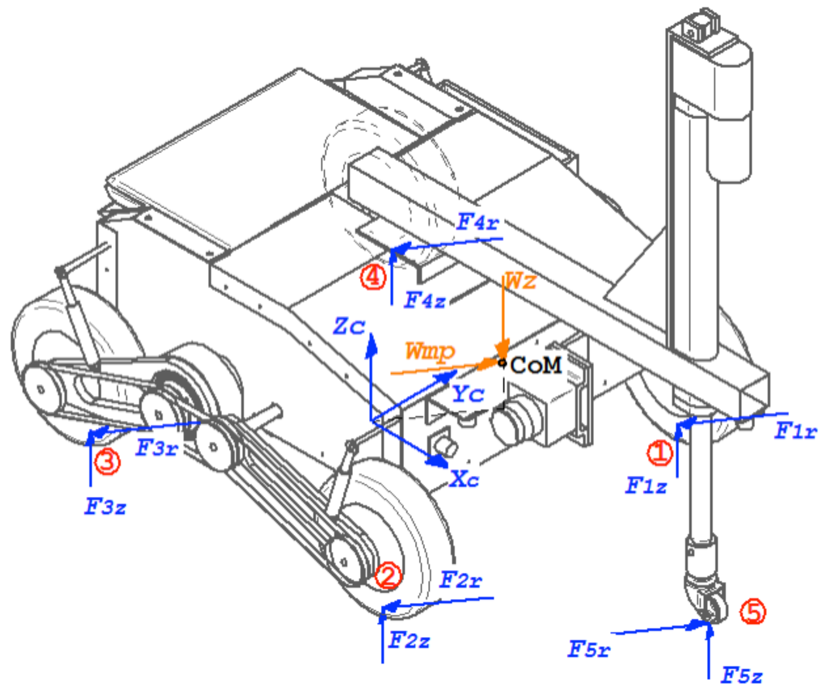
SLIDE-DOWN MARGINS

➢ FORCE BALANCE:

$$\sum_{\forall i} F_{ir} \leq \mu \sum_{\forall i} F_{iz} \Rightarrow$$

$$\hat{I}_s = \frac{\mu \left| \sum_{\forall i} F_{iz} \right| - \left| \sum_{\forall i} F_{ir} \right|}{\mu \left| \sum_{\forall i} F_{iz} \right|}$$



where F_{iz} is the normal force of the i^{th} wheel on the inclined plane.

➢ Valid with or without caster wheels in contact with the ground.

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SLIDE-DOWN MARGINS

- PRACTICAL FORCE BALANCE:

$$I_s = \frac{\mu \left| W_z - \sum_{\forall j} F_{jz} \right| - \left| W_{mp} \right|}{\mu \left| W_z - \sum_{\forall j} F_{jz} \right|}$$

where

$$W_z = W \cos(\phi) \cos(\alpha)$$

$$W_{mp} = W \sqrt{\sin(\phi)^2 + \cos(\phi)^2 \sin(\alpha)^2}$$

W is the weight of the vehicle and F_{jz} is an estimation or measure for the jth caster wheel.

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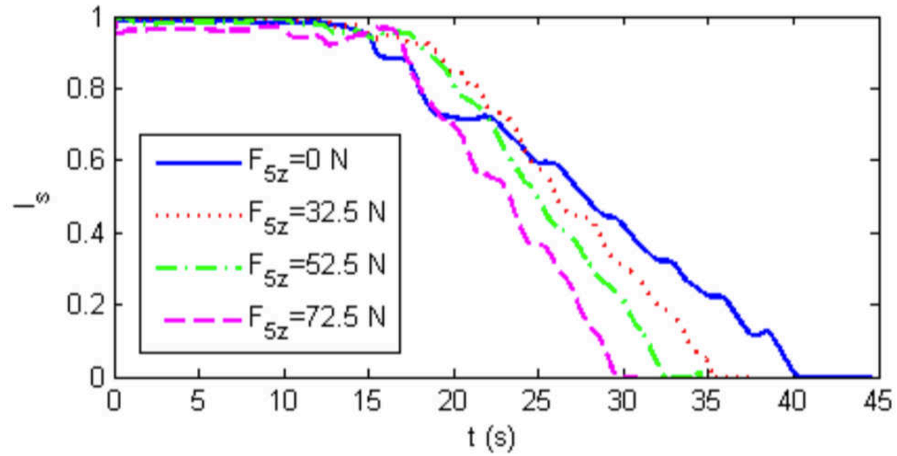
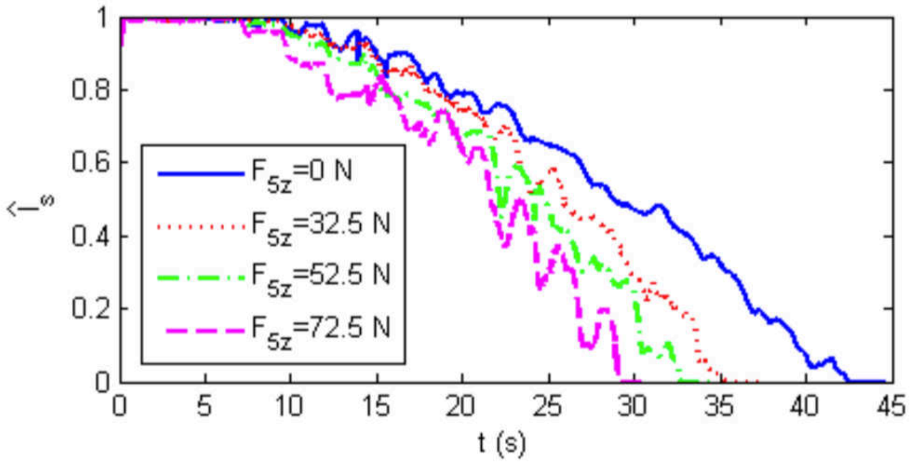
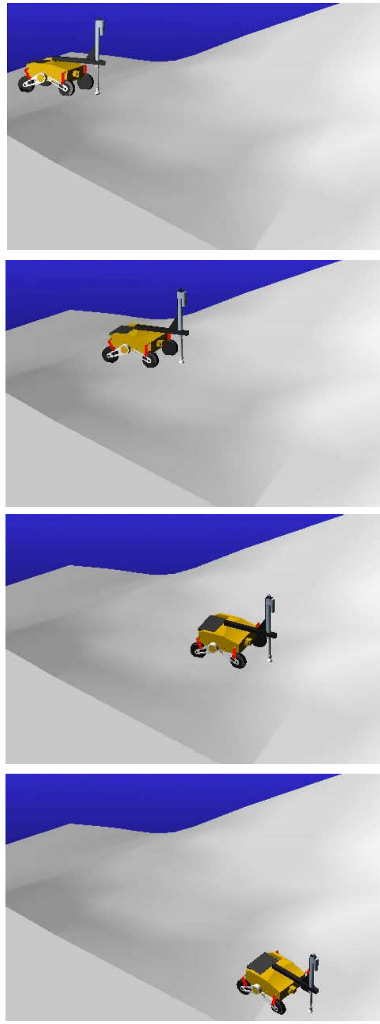
ADAMS SIMULATIONS

- STRAIGHT LINE MOTION: with μ= 0.5 and increasing roll:







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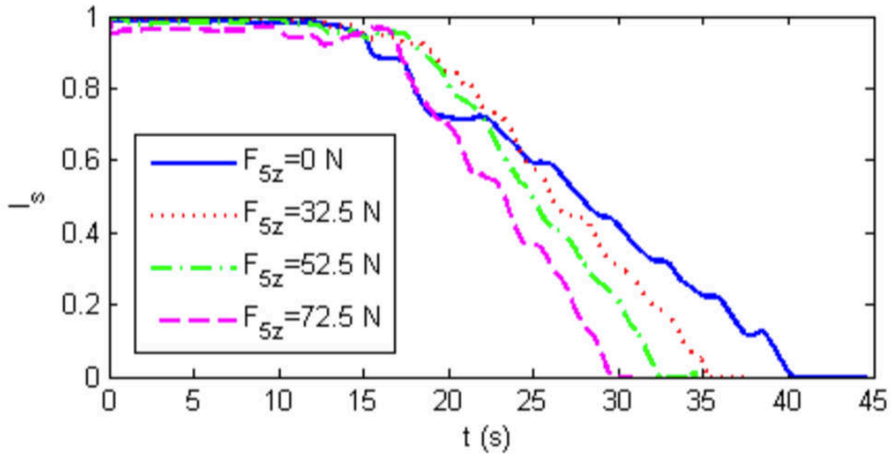

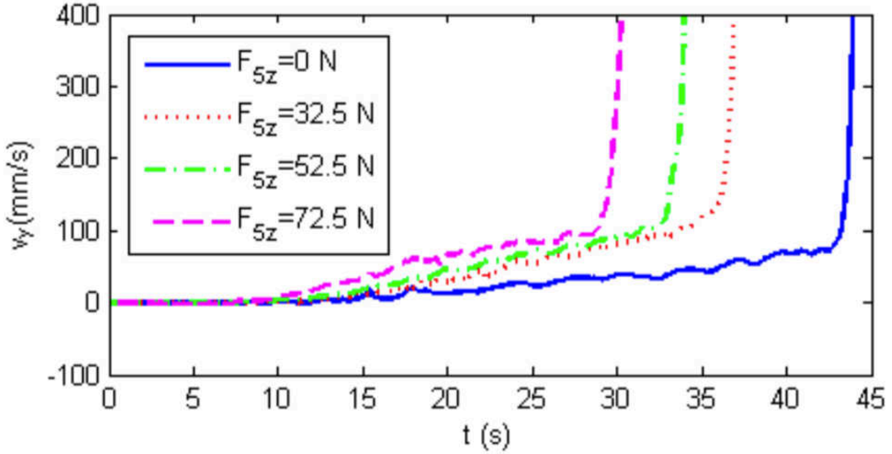

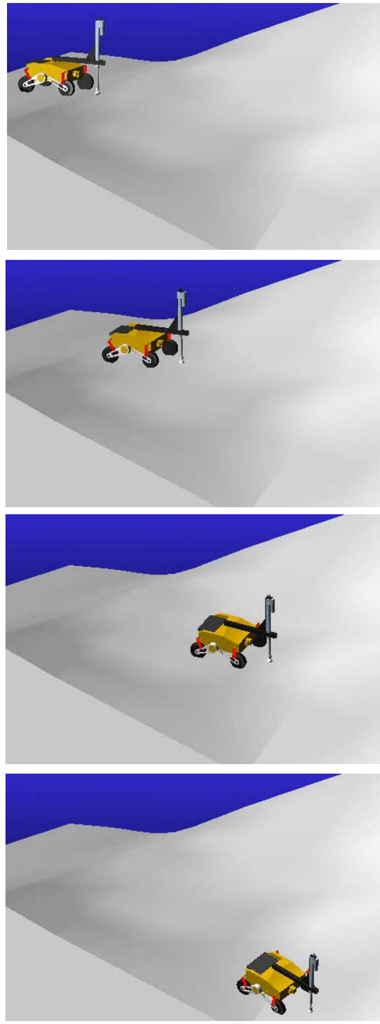

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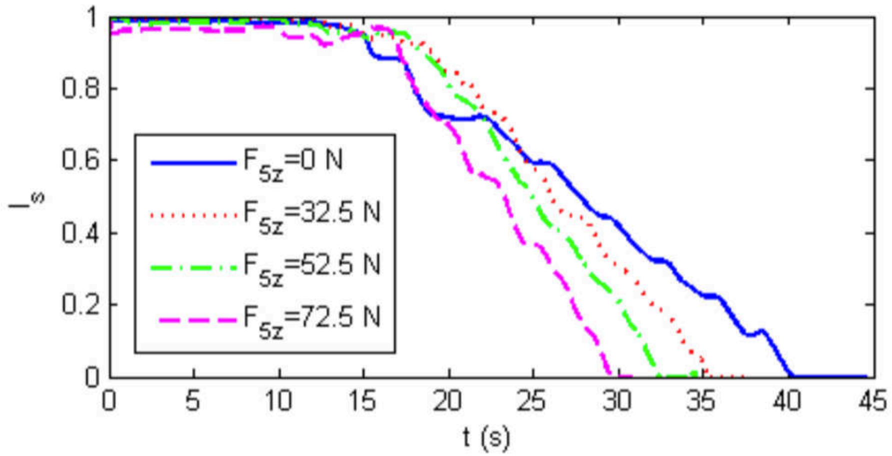
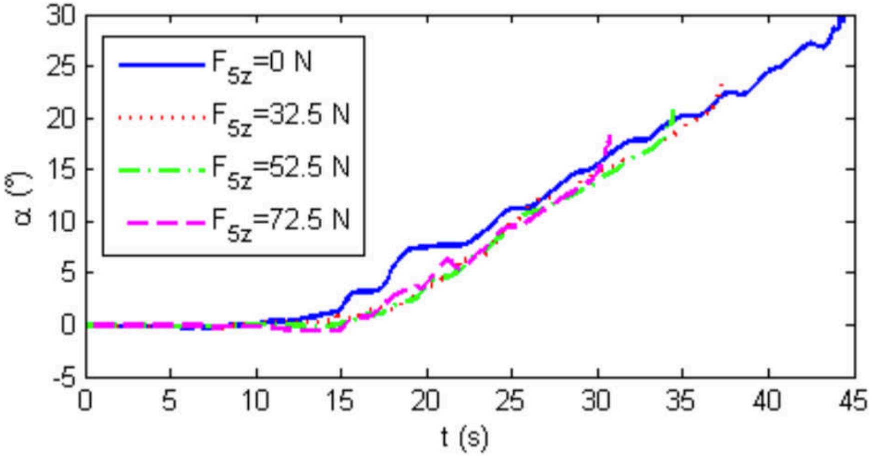
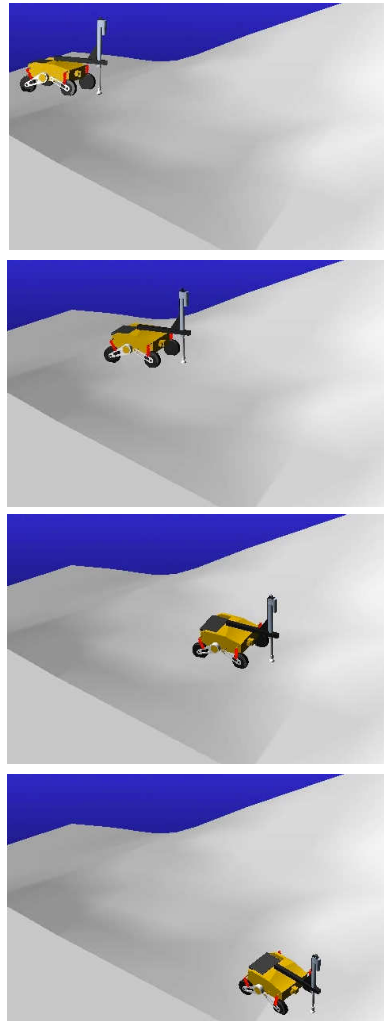
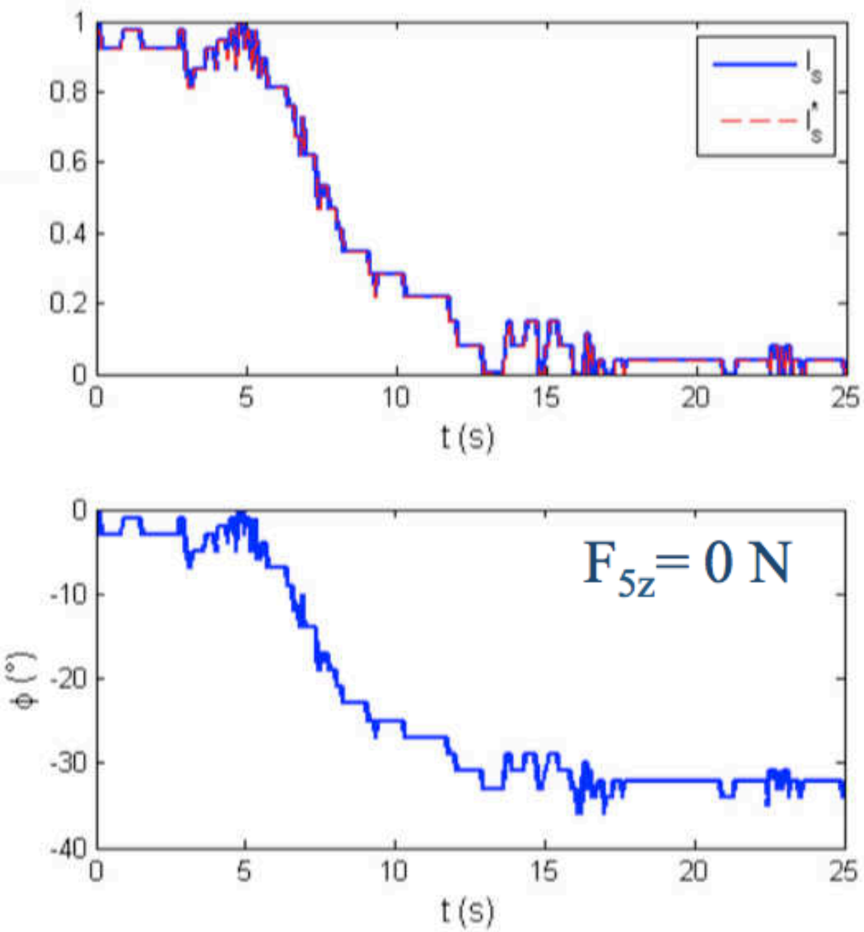






EXPERIMENTAL RESULTS

- STRAIGHT LINE MOTION: with $\mu \approx 0.65$ and increasing pitch:



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EXPERIMENTAL RESULTS

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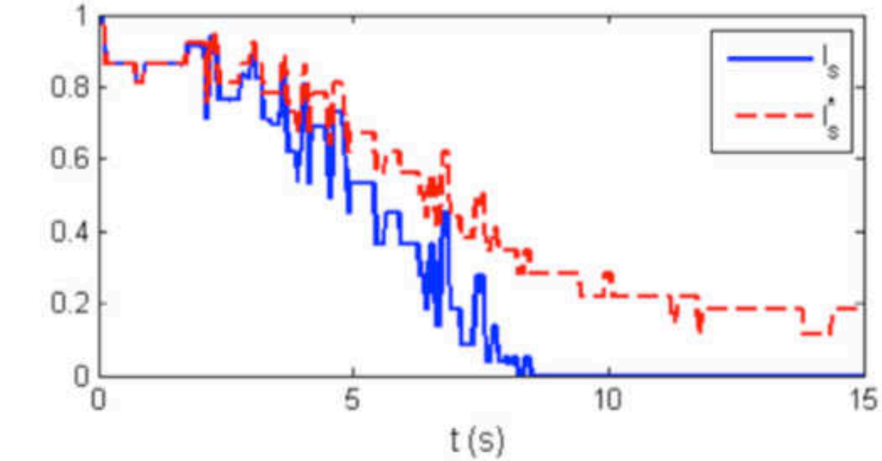

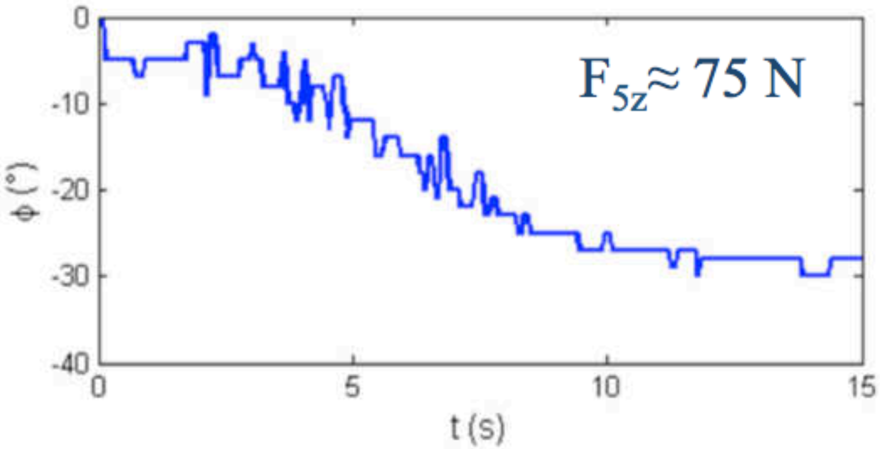

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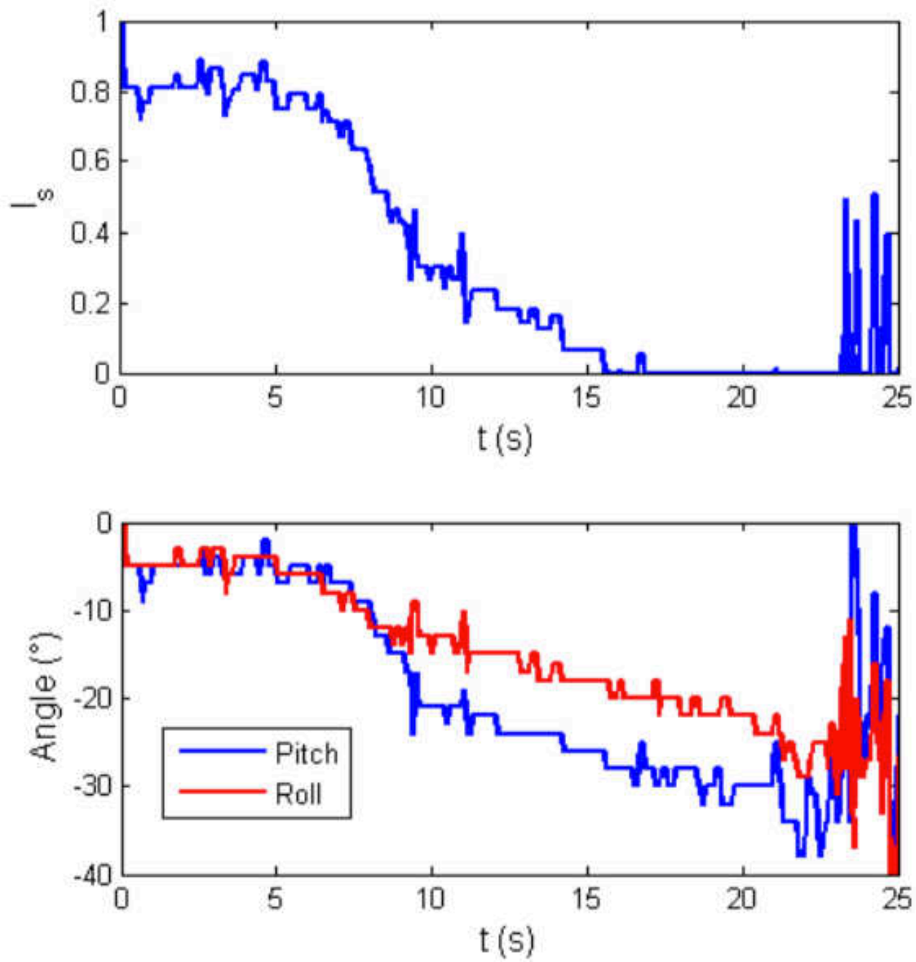
EXPERIMENTAL RESULTS

- STRAIGHT LINE MOTION: with increasing roll and pitch, and F_{5z}=0:



CONCLUSIONS

- Slide-down prevention for wheeled robots is proposed with an easy to compute margin for a given ground-wheel friction coefficient.
- The slide-down margin is based on vehicle' roll and pitch angles, and the estimation or measurement of caster normal forces.
- This approach has been successfully tested with ADAMS simulations and experiments on a skid-steer robot with a caster-leg mechanism.

FUTURE WORK

- The slide-down margin could be applied for remote operation warnings as well as for motion control and path planning.
- It can be useful to estimate the soil-wheel friction coefficient online with inertial measurements.
- It is necessary to study the influence on slide-down of turning with skid-steering and of non-swivel casters.