ActiSurTT

Dispositif actifs pour la sécurité des véhicules en environnement tout-terrain

Low cost active devices to estimate and prevent off-road vehicle from rollover

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Motivations and work context

❖ **Driving difficulties in off-road environment**

- Driving agricultural vehicles is one of the most dangerous professionnal activity
- 50% of fatal accidents are due to rollover
- Mainly due to a difficult manœuvre in a varying driving conditions

❖ **Passive protective structures are not always relevant**

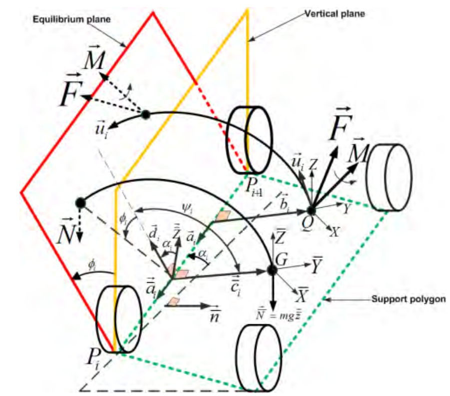
❖ **Development of active safety and driving assistance devices to avoid rollover risk**

- Anticipate for rollover situations
- Warn the driver of hazardous conditions
- Correct the vehicle dynamics in order to avoid the accident
- Use low cost sensors and easy to plug

Towards choosing a metric of stability

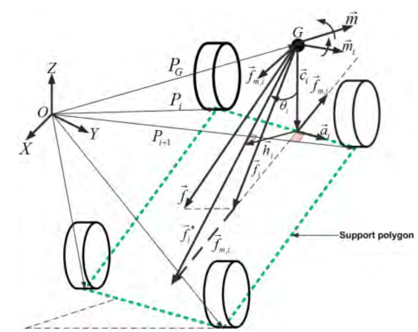
❖ Dynamic Energy Stability Measure (DESM)

- Theoritical accuracy
- Anticipate naturally the risk
- Implementation difficult and time consumming
- Numerous expensive sensors required



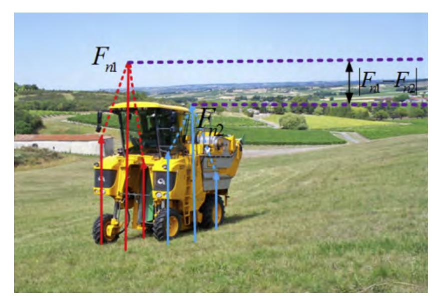
❖ Force Angle Stability Measure (FASM)

- Theoritical accuracy
- Implementation difficult and time consumming
- Numerous expensive sensors required



❖ Lateral Load Transfer (LLT)

- Physical meaning and Simple vehicle models required
- Computational simplicity and Easy adjustabke treshold
- Low cost sensing equipment



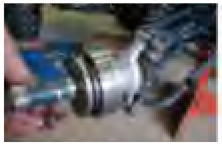
$$LLT = \frac{F_{n1} - F_{n2}}{F_{n1} + F_{n2}}$$

Lateral Load Transfer Direct measurement

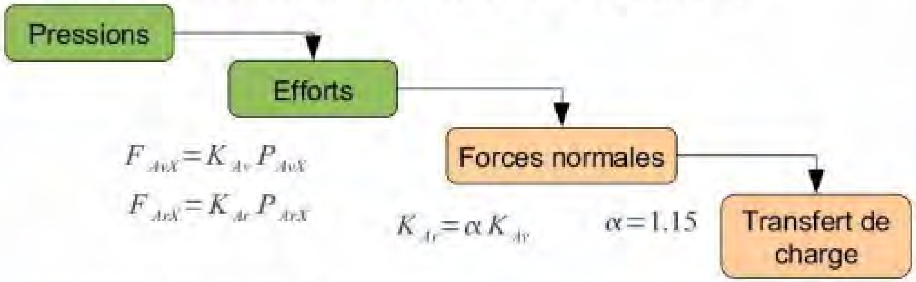
❖ Several kind of sensors

- **Tire deformation measurement**

- **Cell Forces in wheel/rim**



- **Pressure in acuated shock absorber**



$$F_{AvX} = K_{Av} P_{AvX}$$

$$F_{ArX} = K_{Ar} P_{ArX}$$

$$K_{Ar} = \alpha K_{Av} \qquad \alpha = 1.15$$

$$TC_{lat} = \frac{F_{AvG} + F_{ArG} - F_{AvD} - F_{ArD}}{F_{AvG} + F_{ArG} + F_{AvD} + F_{ArD}}$$

$$TC_{lat} = \frac{P_{AvG} + P_{AvD} - \alpha(P_{ArG} + P_{ArD})}{P_{AvG} + P_{AvD} + \alpha(P_{ArG} + P_{ArD})}$$

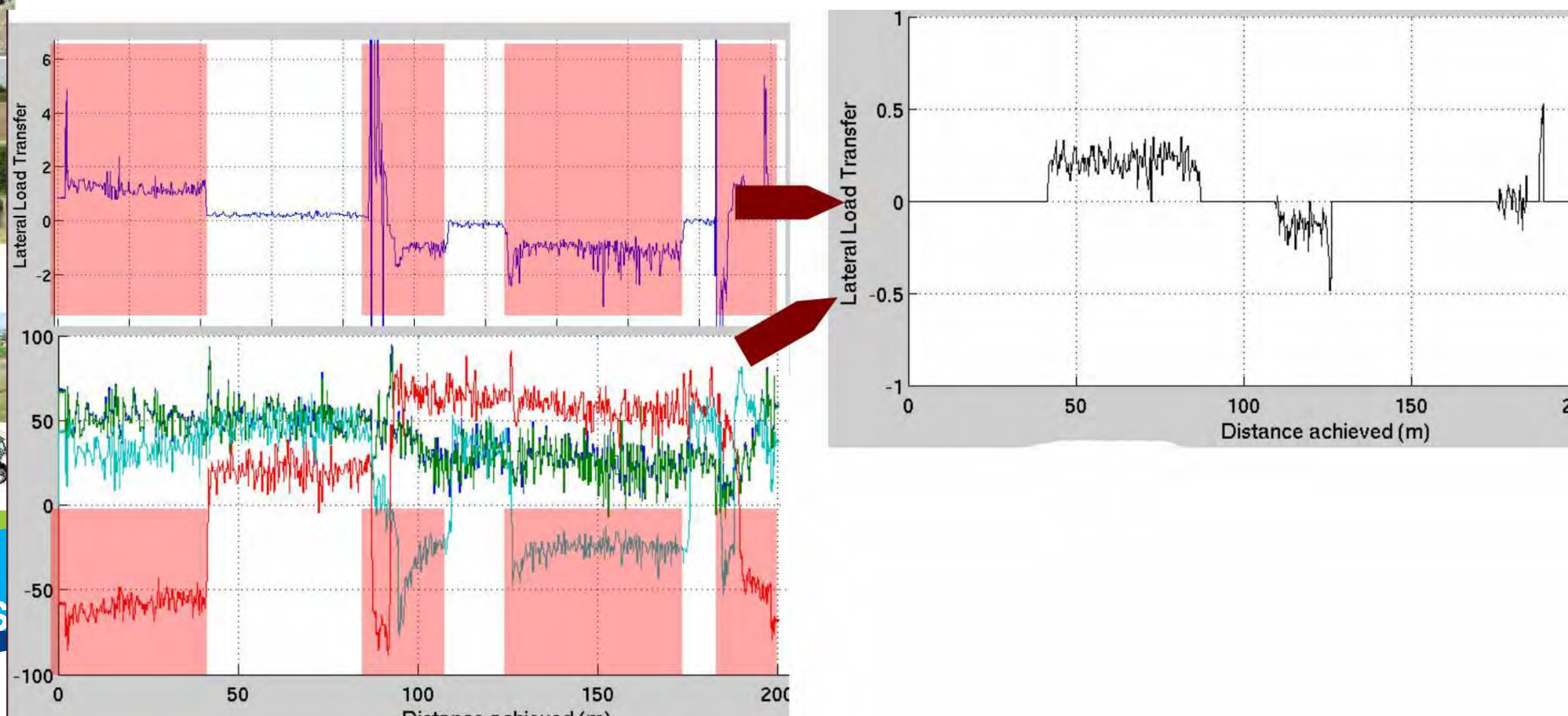
Lat (moy)=0.0241 0.05

Longi(moy)=-0.22 -0.26

Lateral Load Transfer Direct measurement

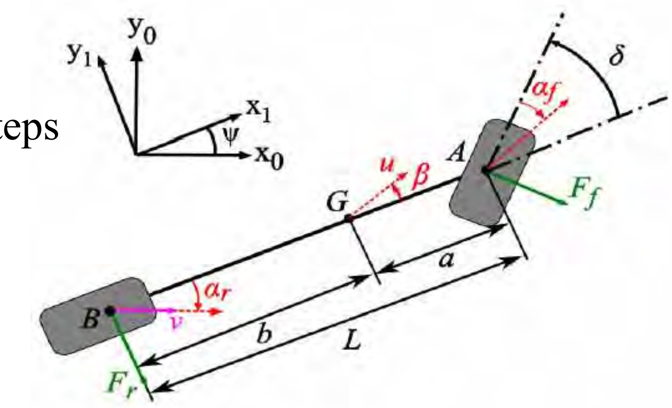
- ❖ Pressure measurement in cylinder
  - **Not always relevant**
    - **Saturation**
    - **Motion**

- ❖ Unavailability easily detectable

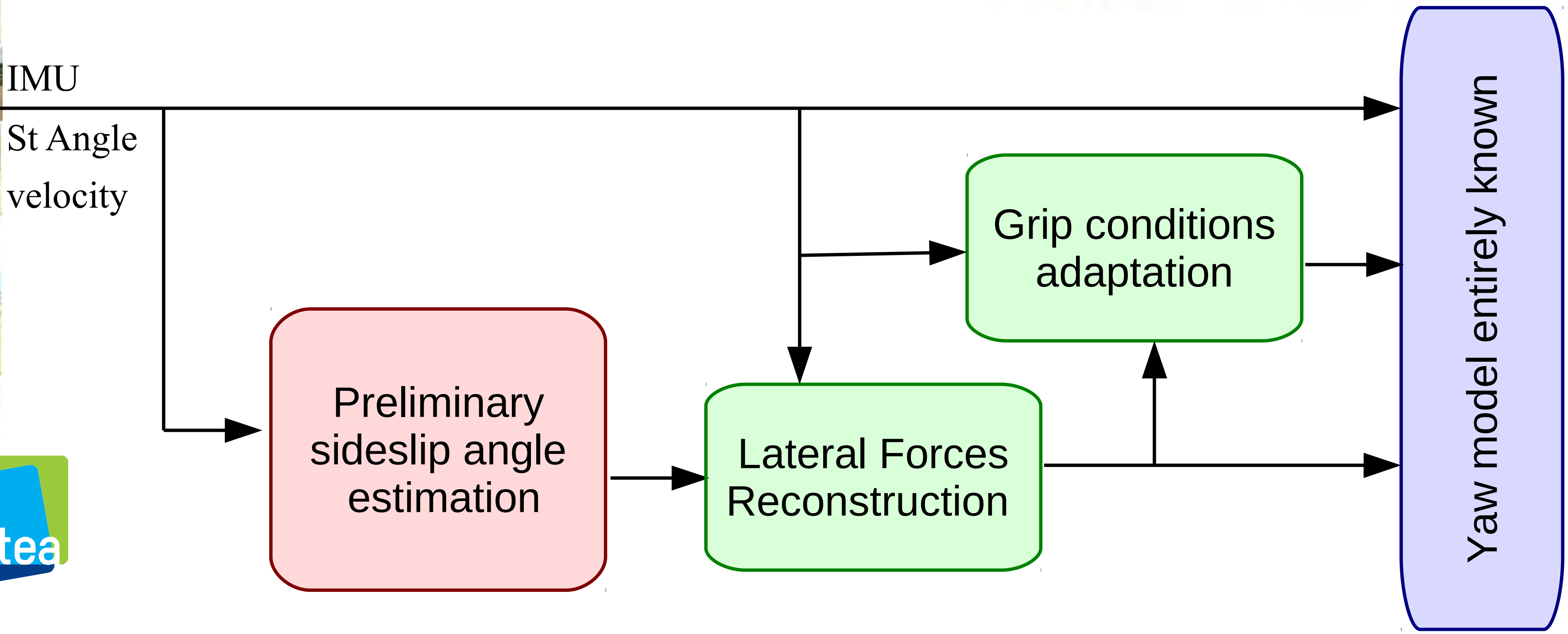


Indirect estimation of Lateral Load Transfer

❖ Step 1: Yaw rate dynamic (grip conditions)

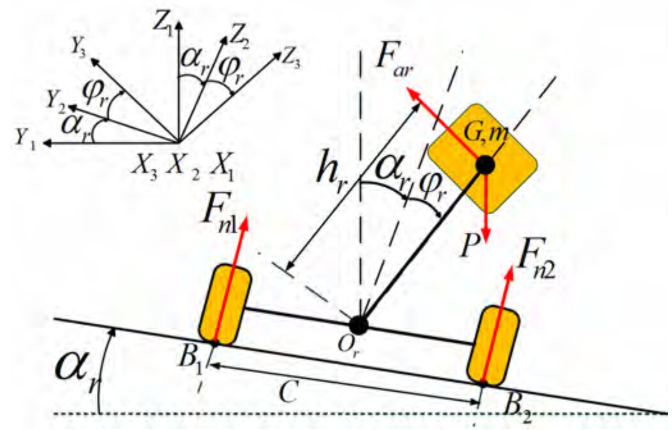


- Observation of sideslip angle and yaw rate in several steps
  - S1: Kinematic observation of global sideslip angle
  - S2: Grip conditions adaptation
  - S3: Variable (sideslip angle) computation
  - S3': Prediction of future state



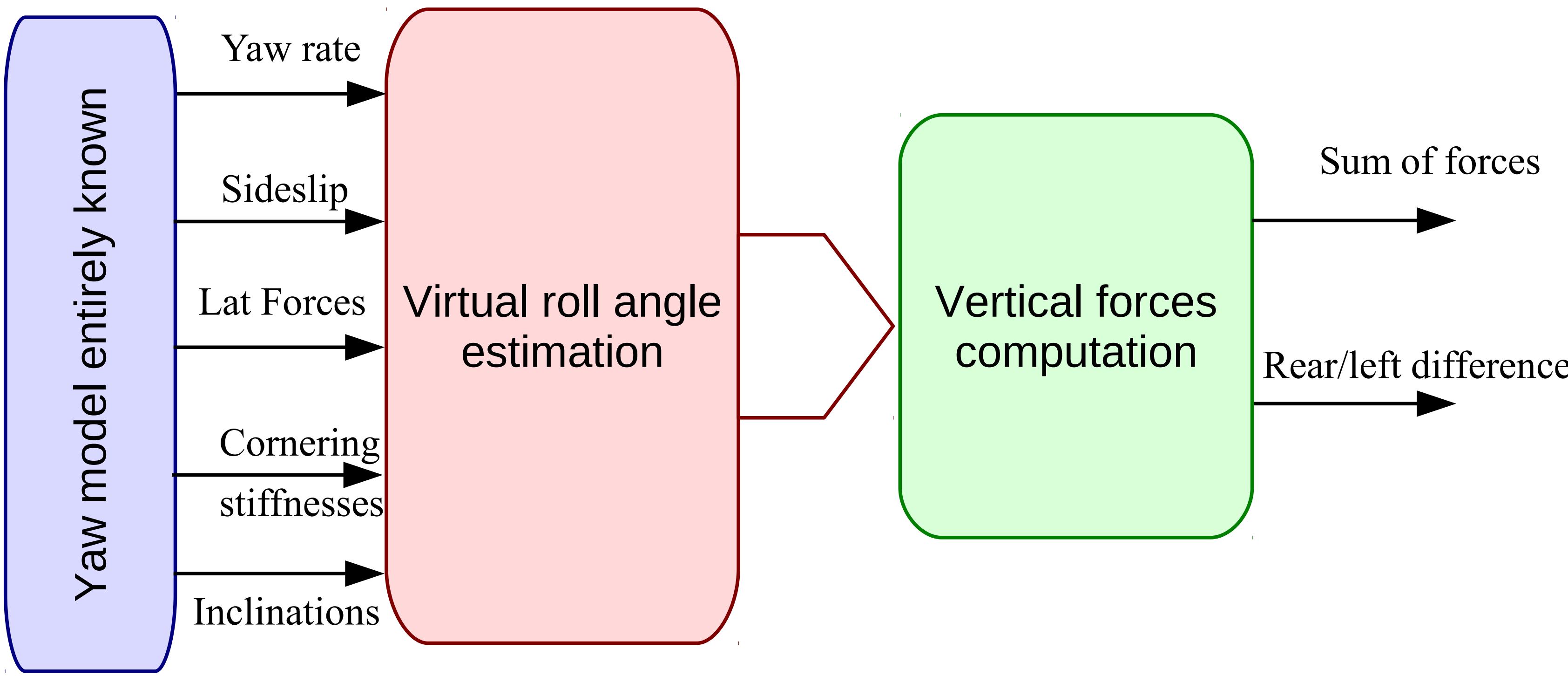
Indirect estimation of Lateral Load Transfer

❖ Step 2: Roll model dynamic (risk estimation)



- Observation roll and LLT

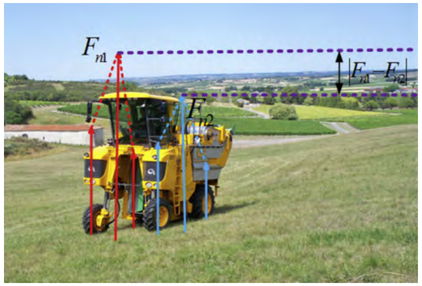
  - S0: Yaw dynamics variables
  - S1: Virtual roll angle estimation
  - S2: Vertical forces repartition



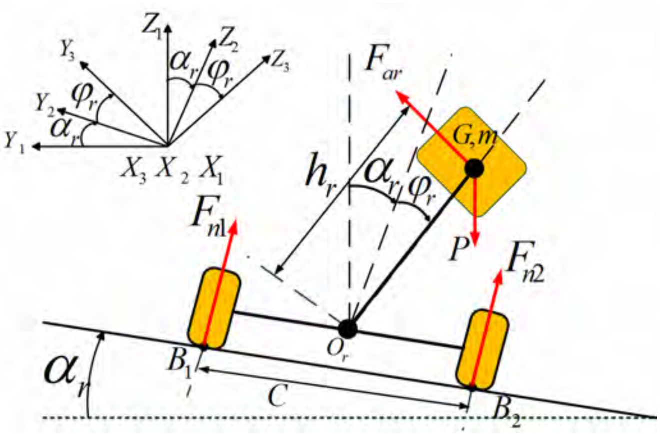
Lateral Load Transfer estimation via the roll vehicle model

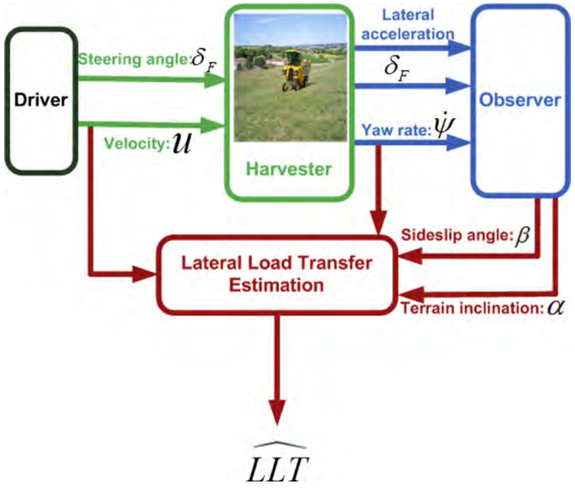
❖ Metric formulation and interpretation

- $$\mathrm{LLT} = \frac{F_{n1} - F_{n2}}{F_{n1} + F_{n2}}$$
- LLT is within [-1 1]
- Wheels lifted off when |LLT|=1



❖ **Metric estimation**

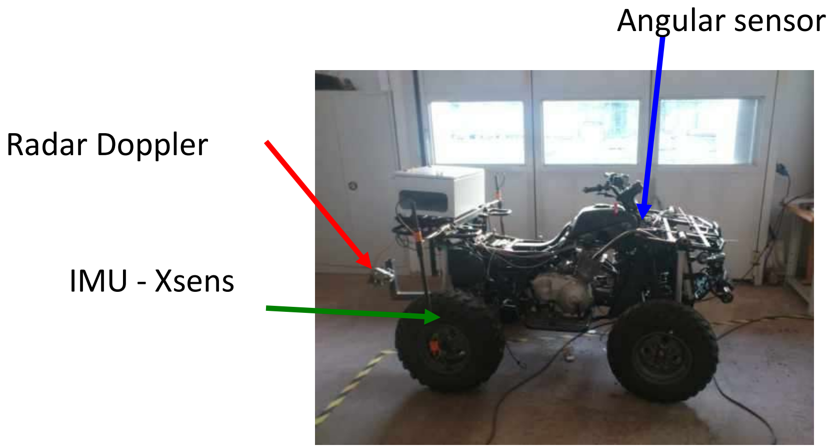


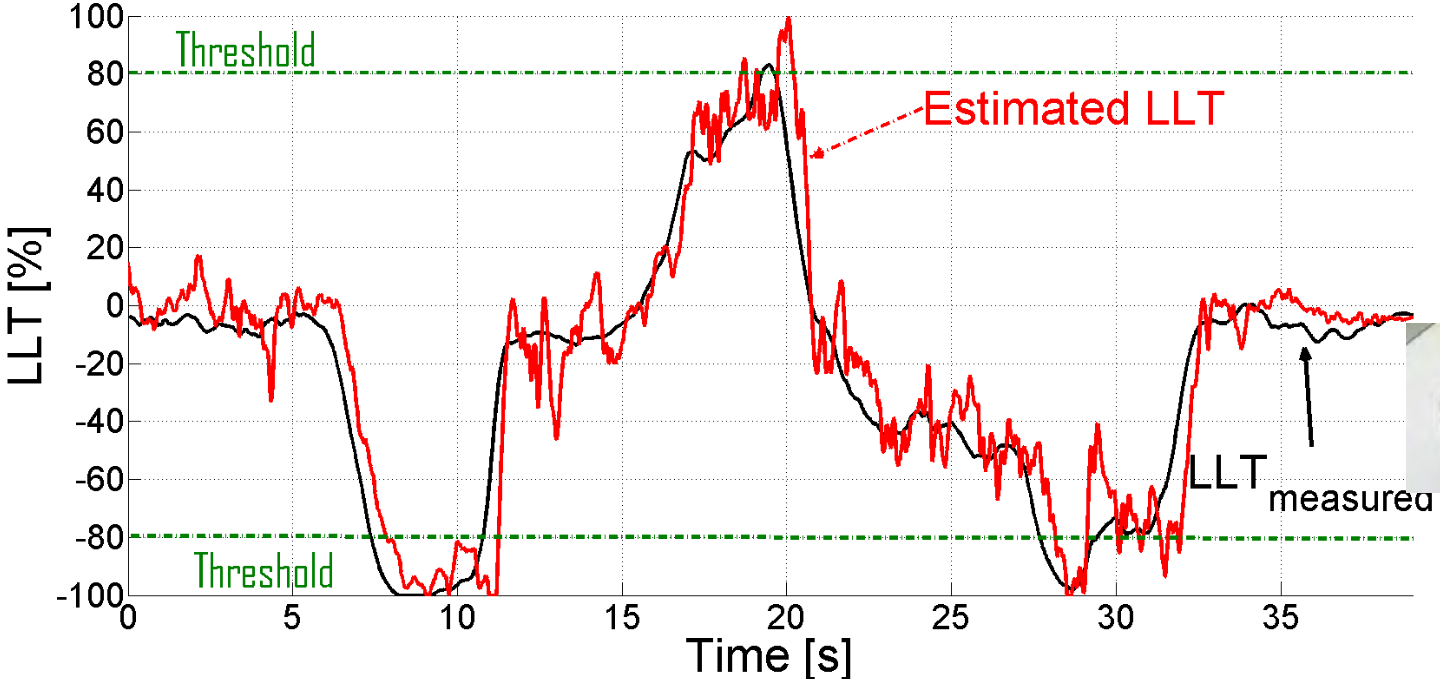


$$F_{n1} + F_{n2} = m\left(-h\ddot{\gamma}\sin\varphi - h\dot{\gamma}^2\cos\varphi + g\cos\alpha - \frac{F_a}{m}\sin\varphi - h\dot{\psi}^2\sin\gamma\sin\alpha + u\dot{\alpha}\sin\beta - u\dot{\psi}\cos\beta\sin\alpha\right)$$

$$F_{n1} - F_{n2} = \frac{2}{c}\left(I_x\ddot{\gamma} + (I_z - I_y)\dot{\psi}^2\sin\gamma\cos\gamma - h\sin\varphi(F_{n1} + F_{n2})\right)$$

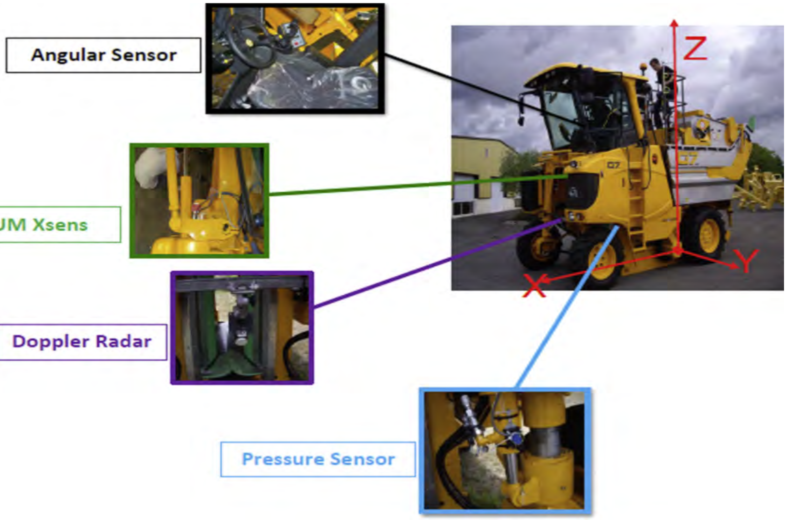
Estimation results in high dynamics

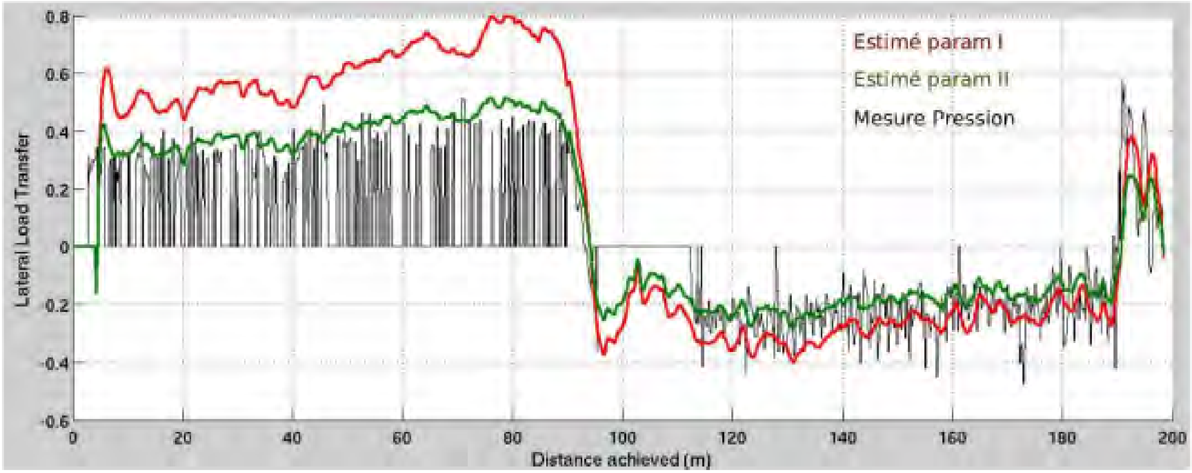




Estimation sensitivity

❖ Modification of parameters





Actual mass = 10.2T

Mass param 1= 10T

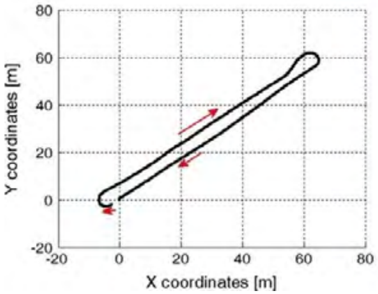
Mass param 2 = 12T

9t<Mass<12t

1.4m<CoG elevation <2m

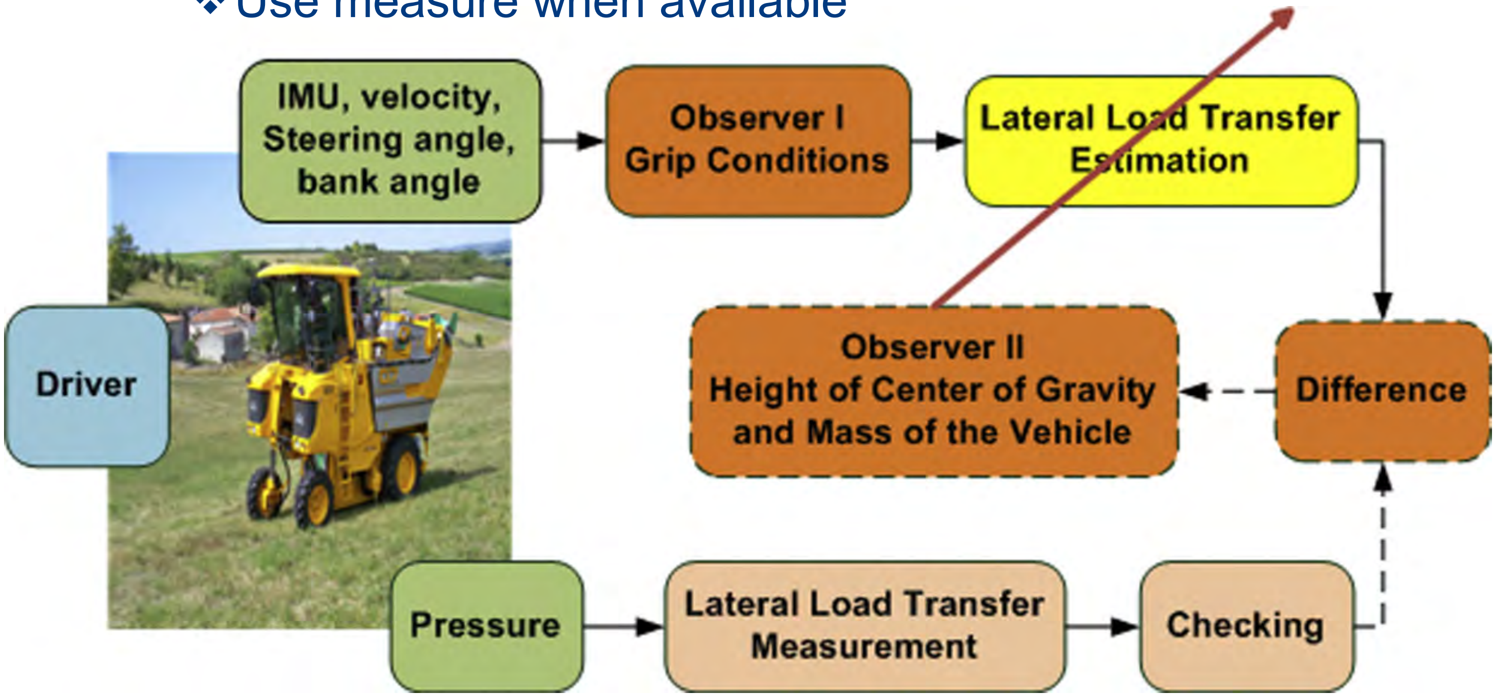
❖ Parameters may be changed during works

- Mass variation during harvesting
- Elevation of center of gravity due to cylinder action



Vehicle parameters adaptation for robustly estmating the risk of rollover

❖ Use measure when available



❖ To adapt model parameters for estimation

- Global mass of the vehicle
- Elevation of the centre of gravity

Detail of parameters adaptation when measure is available

❖ Newton raphson adaption on the lateral load transfer

- Error computation
- Computation of parameter variation
- Ensuring the convergence
- Update parameter

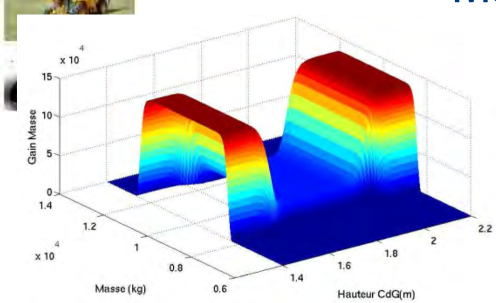
$$e = LLT - L\bar{L}T$$

$$\dot{h} = \gamma \frac{\partial\, LLT}{\partial\, h} e$$

$$e \rightarrow 0$$

$$h = h + dt\, \dot{h}$$

❖ May be used for both parameters pending on some criteria



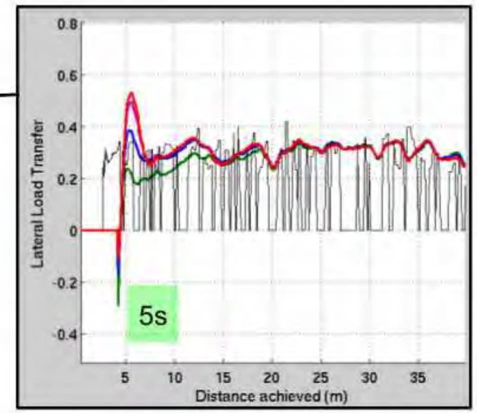
Fast/slow variation

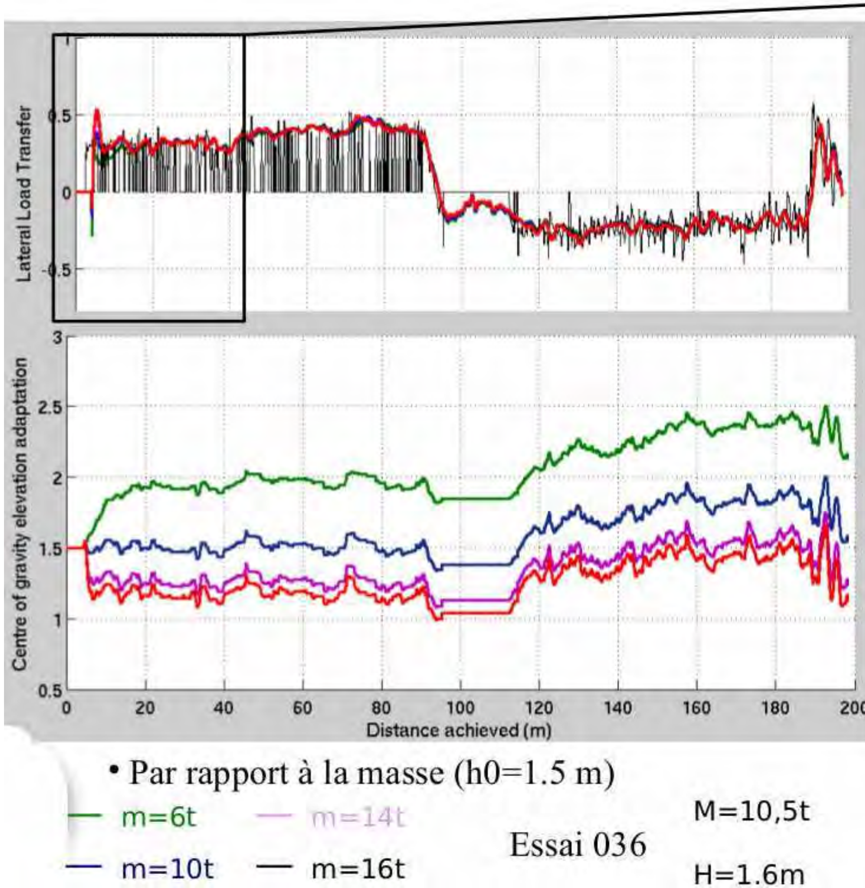
Pending on parameters boundaries

$$\begin{cases} \dot{\hat{h}} & = -\tau_1(.)\ e\ \frac{\partial \widehat{LLT}}{\partial h}(\hat{h}, \hat{m}) \\ \dot{\hat{m}} & = -\tau_2(.)\ e\ \frac{\partial \widehat{LLT}}{\partial m}(\hat{h}, \hat{m}) \end{cases}$$

Results on one parameter

❖ Example of centre of gravity elevation adaptation





Interest on the risk assesment

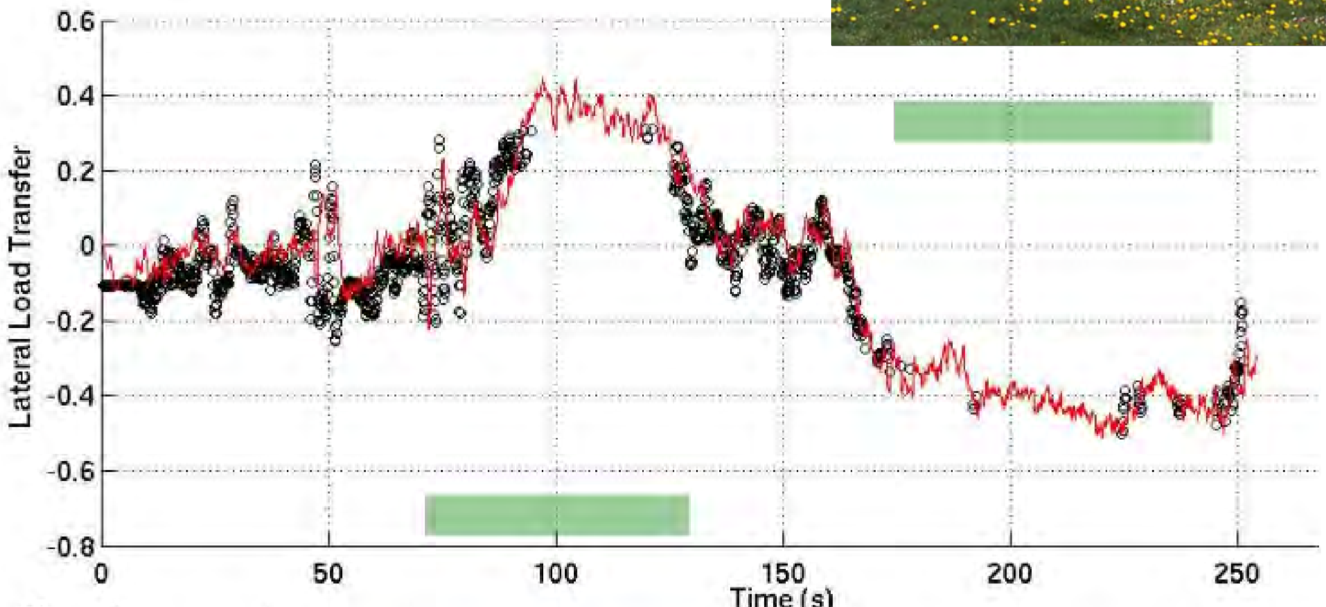
❖ Typical dangerous use

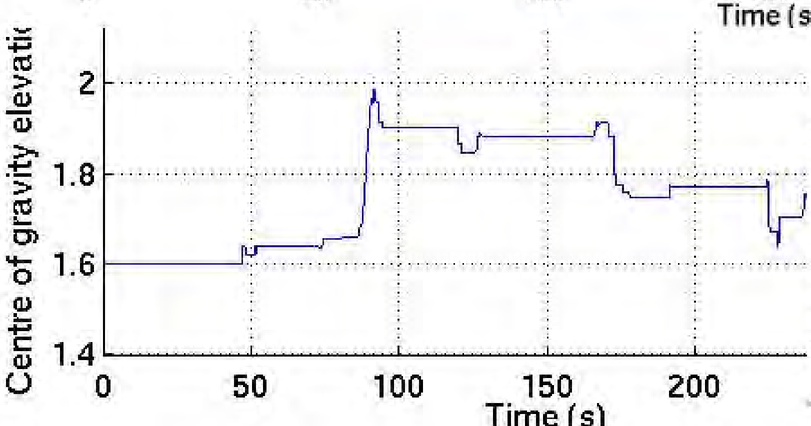


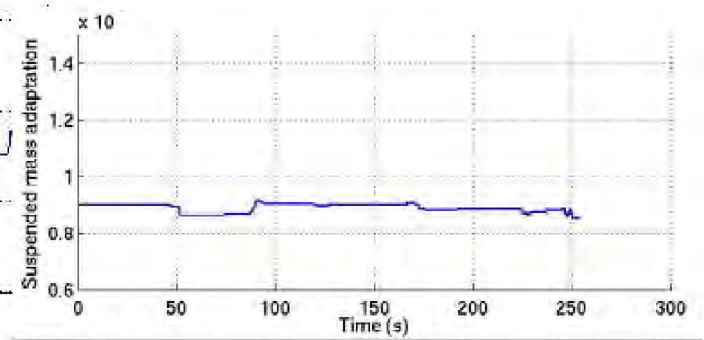




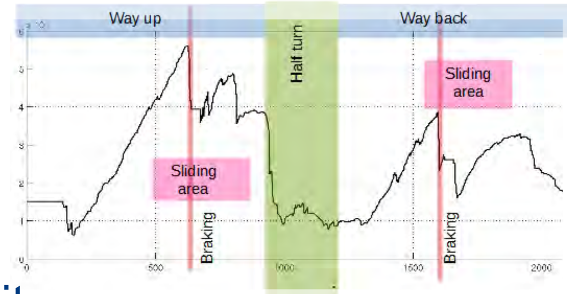






Extension and active safety

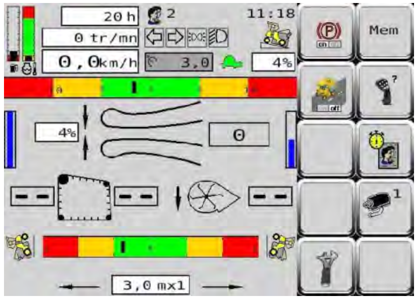


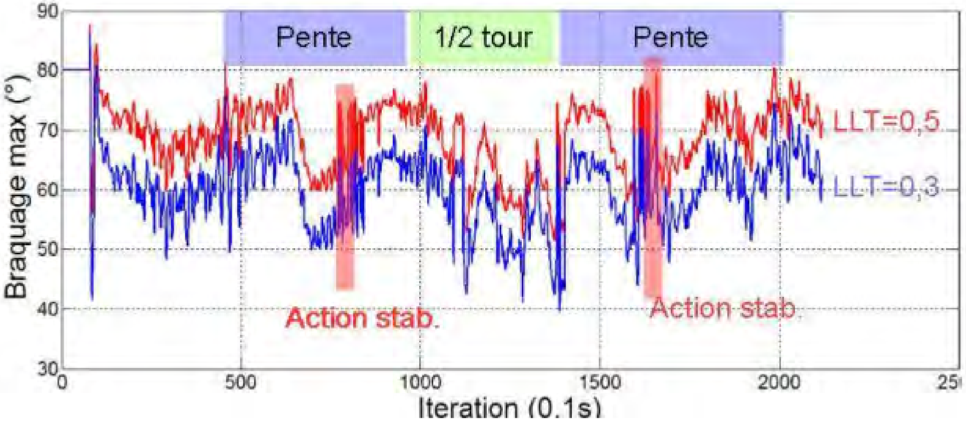
❖ Extension to longitudinal stability and controlability

- Longitudinal grip condition
- Stop distance
- Maximal slope

❖ Model can be used to derive safety workspace

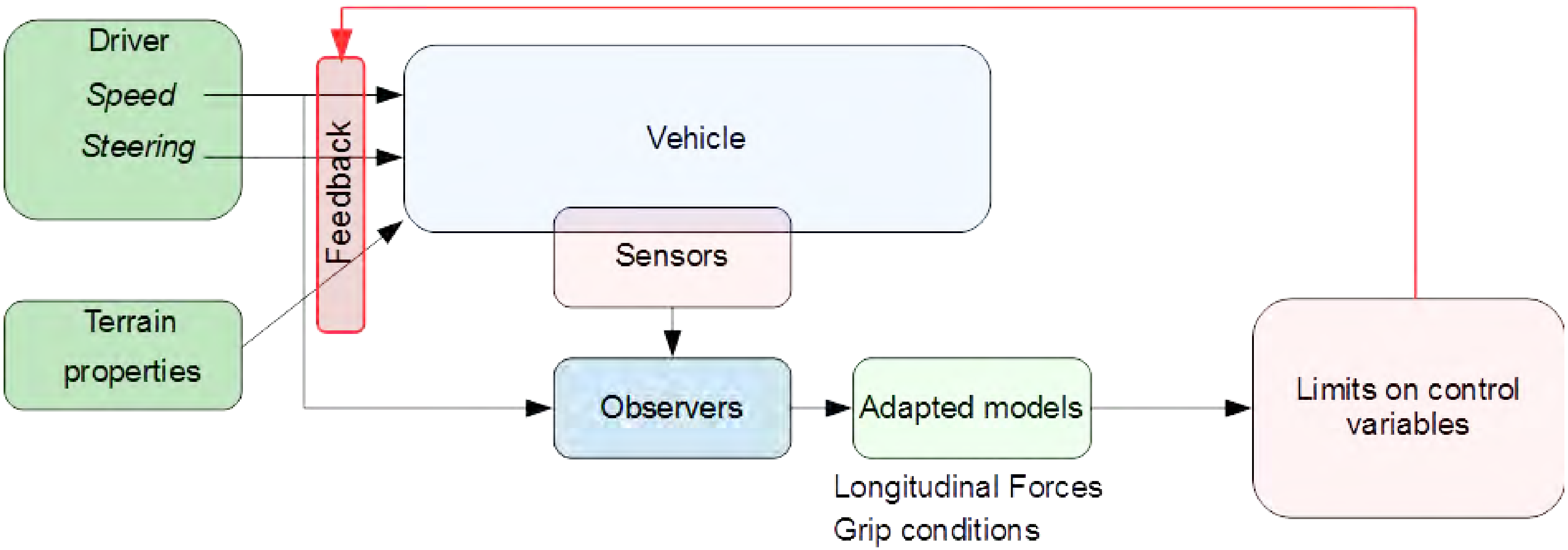
- Maximal admissible speed
- Steering capabilities without rollover
- Climbing capabilities





Active safety and extension

❖ Interaction with driver



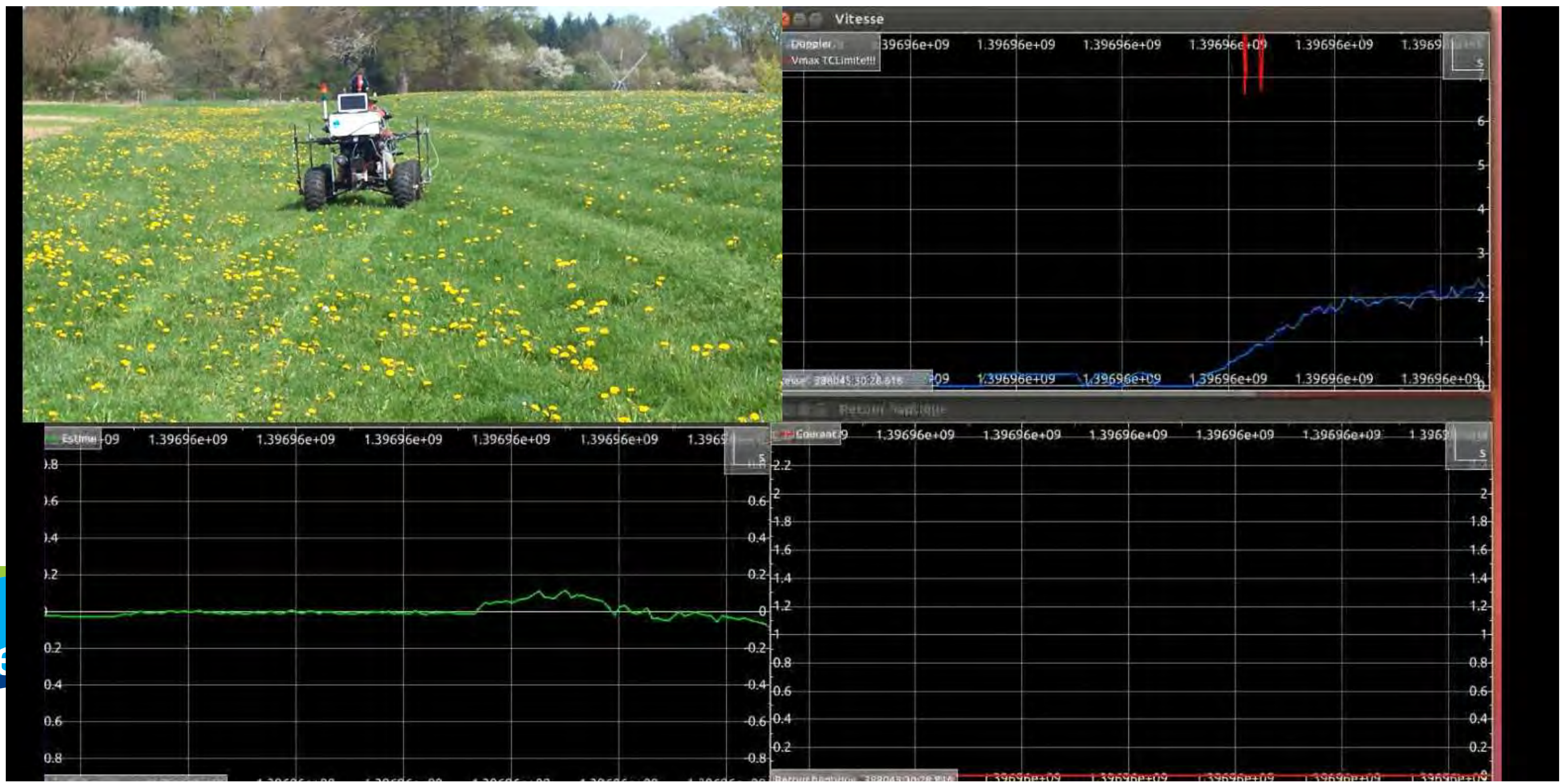
- Visual or sound warning

- Feedback Force on throttle
- Feedback torque on steering wheel
- Automatic action on machines

Active safety and extension

❖ Feedback force on throttle

- Using low cost sensor
- Adaptation on different quad bikes



Conclusion and Perspectives

- ❖ Lateral Load Transfer can be accurately estimated in real time
- ❖ Account for the state of terrain properties, and the machine configuration
- ❖ Indirect measurement of parameters variation
- ❖ Permits to extract stability domain
- ❖ Open the way to active safety devices
- ❖ Under further testing and driver feedback

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