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DEPARTMENT OF
MECHANICAL ENGINEERING

MOTORCYCLE DATA REQUIRED FOR IMPROVING THE REALITY FEELING ON A DRIVING SIMULATOR

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Vi-GRADE - ACCELERATING TOWARDS ZERO PROTOTYPES IN THE MOTORCYCLE INDUSTRY

OUTLINE

Motorcycle dynamic behavior, influence of

- Inertia properties
- Tire characteristics

Measuring the inertia properties of motorcycles

Smart wheels to measure the generalized forces at the hub of a motorcycle

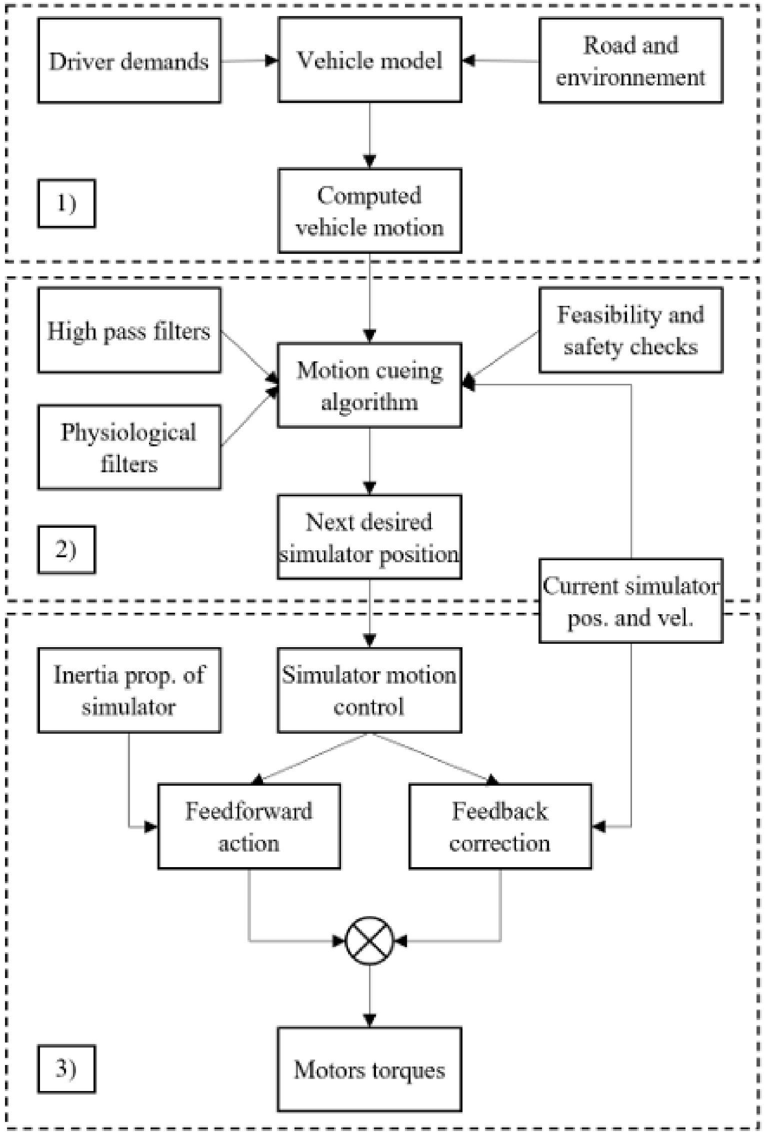
How to provide “reality feel” to driving simulator users

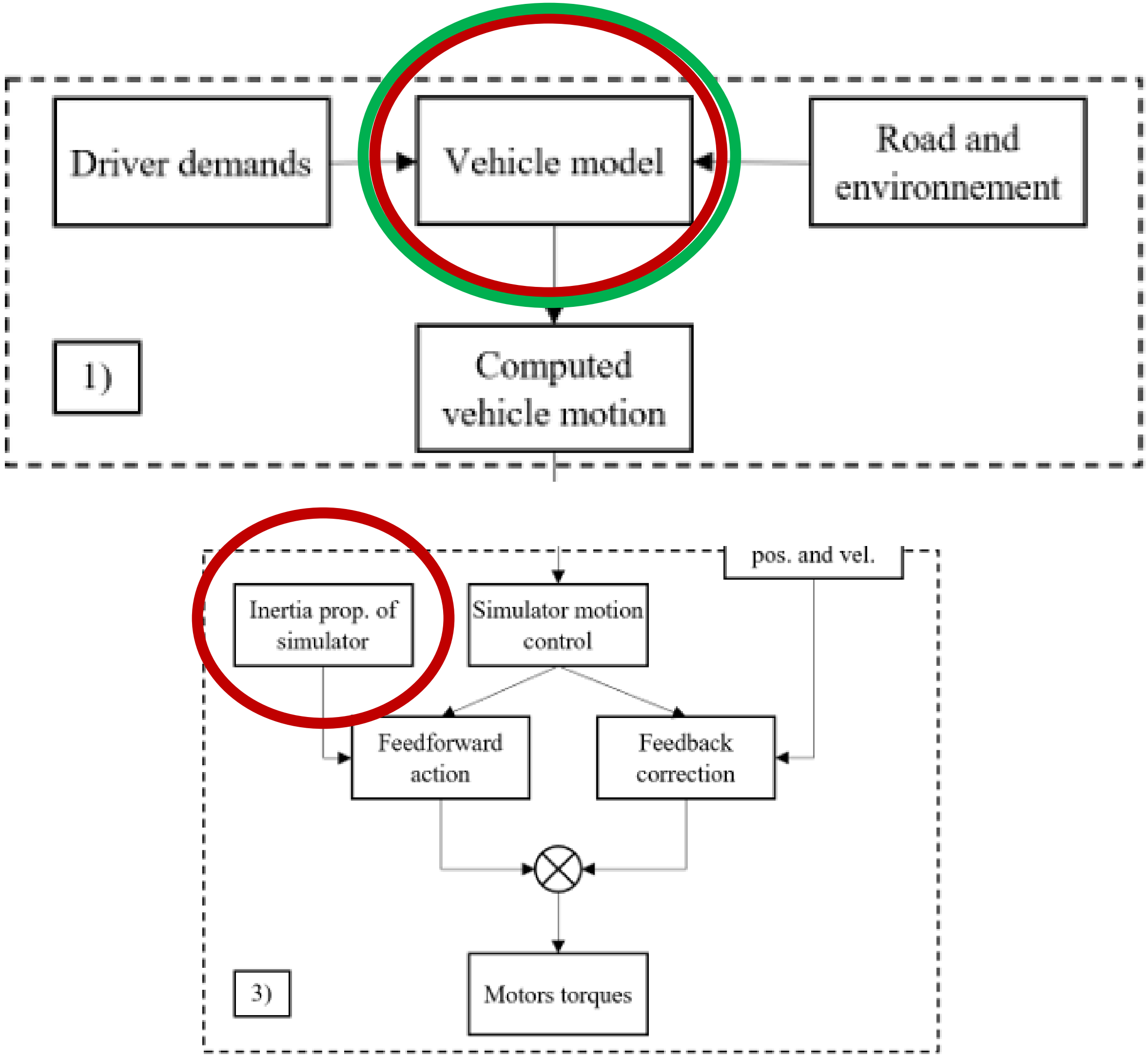
FIDELITY

A key issue for driving simulators is fidelity

the extent to which they emulate driving in the real-world.

DYNAMIC SIMULATOR MOTION CONTROL





GIGO

Garbage in, garbage out. “you get what you put in”. If your data inputs are bad, your simulation outputs will be bad too.

The validity of a vehicle model is dependent on the parameters used to construct it.

If you use garbage parameters and curves to construct the model, then you will get a simulation of a non-existent vehicle with garbage performance.

INTENSINO +

Test rig	InTensino+
Payload range [kg]	50 – 400
Maximum dimensions of the body (LxWxH) [m]	3x1x1(*)
Motion frequency [Hz]	< 5
Peak acceleration during test (min.-max) [m/s^2]	3-10
CG uncertainty (in plane, height) [mm]	± 1.5 - ± 3
Moment of inertia (MOI) uncertainty	± 1%
POI accuracy (% of the maximum MOI of the body)	± 0.5%
MOI and POI resolution (% of the maximum MOI of the body)	0.2 %
Testing time [minutes](**)	< 10

ISO Quality Certification

Encoders
Load Cell

INTENSINO+

II Newton's law

$$\underline{f} = \left[M\left(m,[J],\underline{\theta},\underline{\omega}\right)\right]\cdot \underline{a}$$

At the reference point P

$$\underline{f_P} = \left[M^*\left(m,\underline{X_{PG,1}},[J],\underline{\theta},\underline{\omega}\right)\right]\cdot \underline{a_P}$$

Identification equation

$$\underbrace{\underline{f_P}_{6x1} - \begin{bmatrix} m\cdot \underline{a_P}_{3x1} \\ \underline{0}_{3x1}\end{bmatrix}}_{\underline{b}_{6x1}} = \underbrace{\begin{bmatrix} \left[g\left(m,\underline{\theta},\underline{\omega},\underline{\dot{\omega}}\right)\right]_{3x3} & [0]_{3x6} \\ \left[h\left(m,\underline{\theta},\underline{\omega},\underline{\dot{\omega}}\right)\right]_{3x3} & \left[k\left(\underline{\theta},\underline{\omega},\underline{\dot{\omega}}\right)\right]_{3x6}\end{bmatrix}}_{[a]_{6x9}} \cdot \underbrace{\begin{bmatrix} \underline{X_{PG,1}}_{3x1} \\ \underline{J}_{6x1}\end{bmatrix}}_{\underline{x}_{9x1}}$$

$$\underline{b}_{6x1} = [a]_{6x9} \cdot \underline{x}_{9x1}$$

INTENSINO+

By considering n time instants

$$\begin{bmatrix} \underline{b}_1 \\ \underline{b}_2 \\ \vdots \\ \underline{b}_n \end{bmatrix} = \begin{bmatrix} [a_1] \\ [a_2] \\ \vdots \\ [a_n] \end{bmatrix} \cdot \underline{x} \qquad \Rightarrow \qquad \underline{B} = [A] \cdot \underline{x}$$

Least square estimation

$$\underline{x} = \left([A]^T [A]\right)^{-1} [A]^T \cdot \underline{B}$$

Error evaluation

$$\underline{s}_i \cong \pm\sqrt{p_0^2 \cdot c_{ii}} \quad with \qquad c = \left([A]^T [A]\right)^{-1}$$

$$\underline{v} = [A] \cdot \underline{x} - \underline{B} \qquad\qquad p_0^2 = \frac{\sum_{i=0}^{n} v_i}{n - p}$$

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ISO Quality Certification

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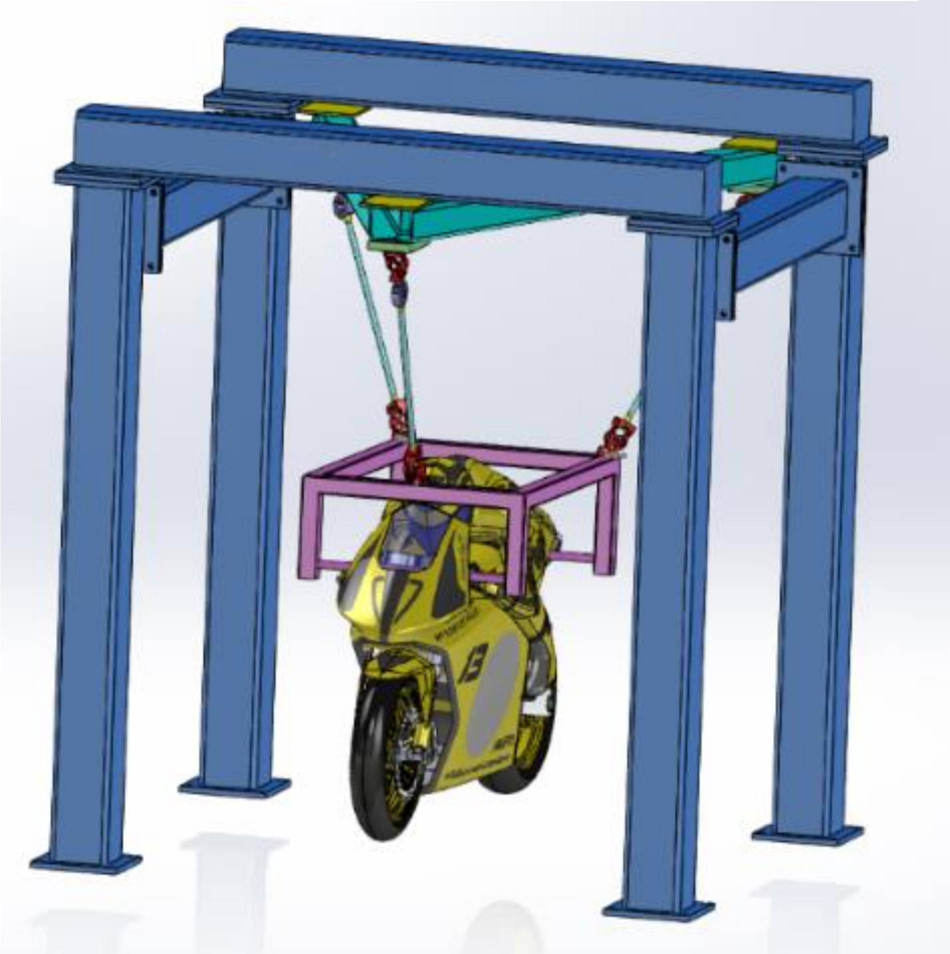
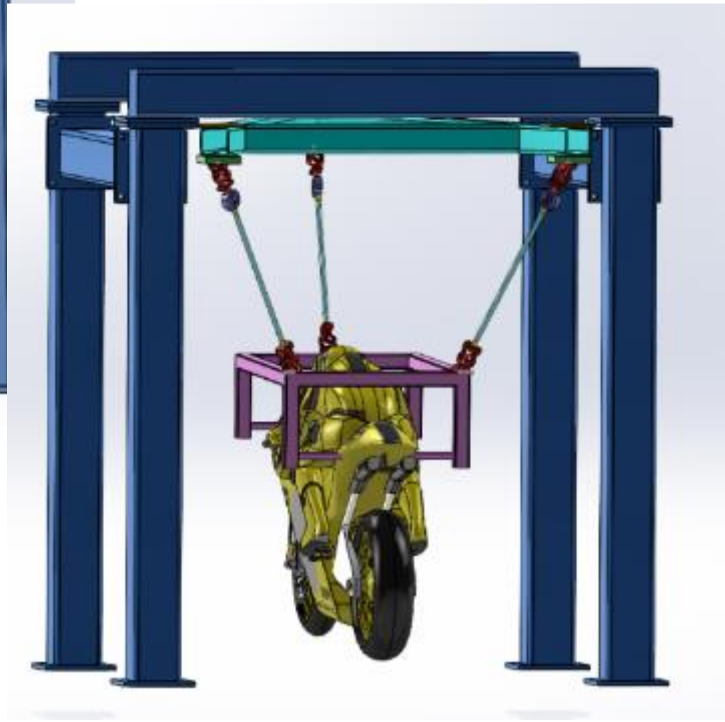
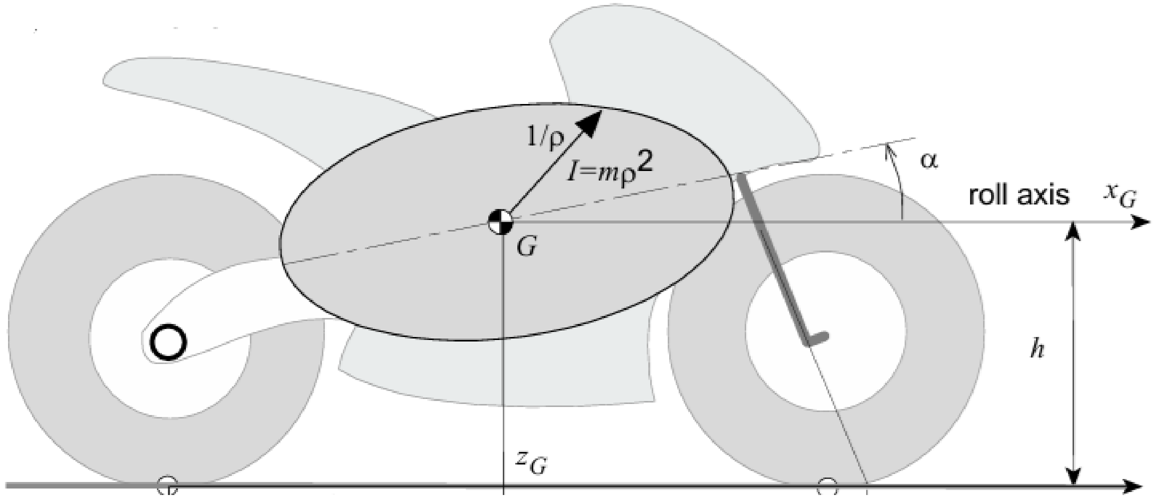




INTENSINO+



I_x=	5.0	kg*m^2
I_y=	41.8	kg*m^2
I_z=	39.1	kg*m^2
α=	1.9	°

INTENSINO+

Dynamic behavior of a racing motorcycle depends on the inertia properties

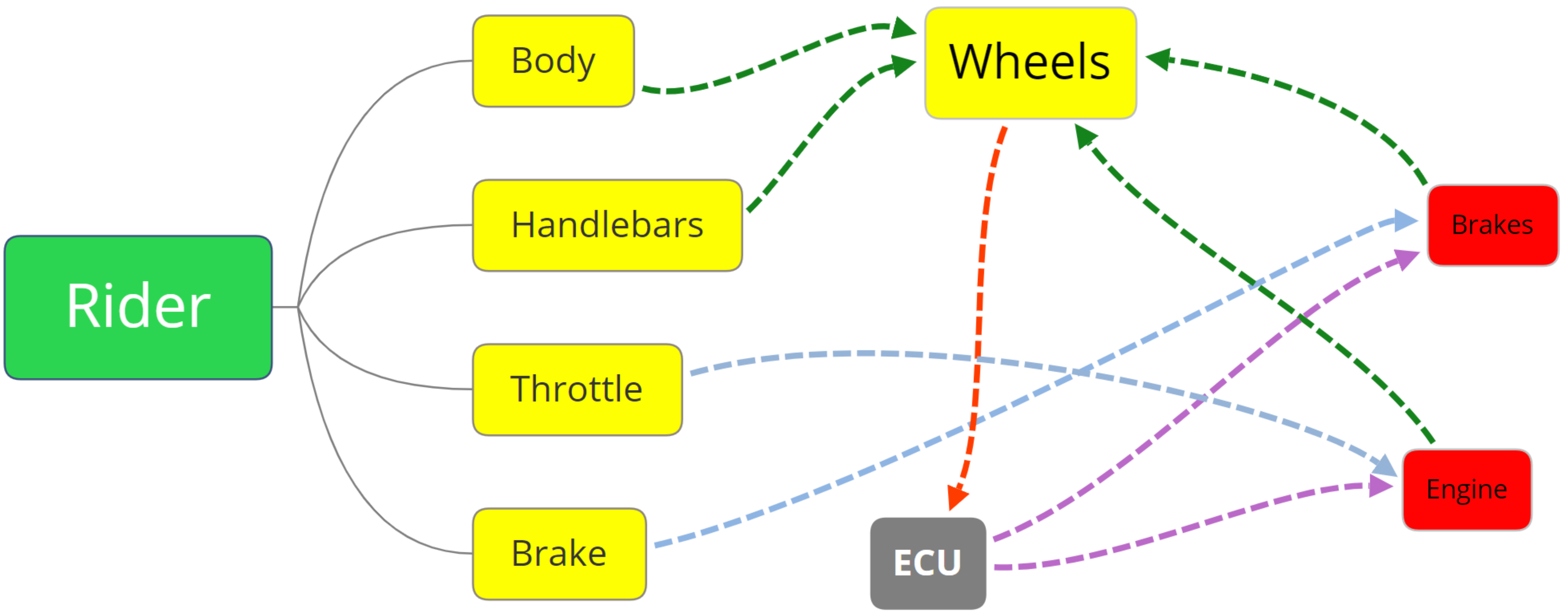
Center of mass position and moments of inertia around the roll and yaw axes are fundamental for analyzing the handling characteristics of the motorcycle.

Roll/Yaw Product of Inertia provides additional information about the coupling between roll and yaw motions.

MOI Accuracy +/- 1% (+/- 2σ), POI Accuracy +/- 0.5 % (+/- 2σ)

Ixx	Iyy	Izz	
5.05 kg m^2	42.2 kg m^2	39.5 kg m^2	POI +/- 0.2 kg m^2 -> α= +/- 0.2°
4.95 kg m^2	41.4 kg m^2	38.7 kg m^2	

SMART WHEEL


Rider
Body
Handlebars
Throttle
Brake
Wheels
ECU
Brakes
Engine

SMART WHEEL - STATE OF THE ART

Loads applied @ Wheels

Lightweight Fatigue Spectra

- Mastinu, G., & Gobbi, M. (2023). Force sensors for active safety, stability enhancement and lightweight construction of road vehicles. *Vehicle System Dynamics*, *61*(9), 2165–2233. https://doi.org/10.1080/00423114.2023.2240447
- Ballo, F., Mastinu, G., and Gobbi, M., "Lightweight Design of a Racing Motorcycle Wheel," SAE Technical Paper 2016-01-1576, 2016, https://doi.org/10.4271/2016-01-1576

Friction Estimation

- Previati, G., Gobbi, M., Mastinu, G., Dell'agostino, S., Edelmann, J., & Plöchl, M. (2016, March). Friction estimation at tyre-ground contact based on the gough-plot for safe autonomous vehicles. In *The Dynamics of Vehicles on Roads and Tracks-Proceedings of the 24th Symposium of the International Association for Vehicle System Dynamics, IAVSD 2015* (pp. 511-520). CRC Press/Balkema. doi: 10.1201/b21185-56
- Edelmann, J., Gobbi, M., Mastinu, G., Ploechl, M., & Previati, G. (2015). Friction estimation at tire-ground contact. *SAE International Journal of Commercial Vehicles*, *8*(2015-01-1594), 182-188.

Tire modelling

- Ballo, F., Gobbi, M., Mastinu, G., and Previati, G. (March 31, 2016). "Motorcycle Tire Modeling for the Study of Tire–Rim Interaction." ASME. *J. Mech. Des*. May 2016; 138(5): 051404. https://doi.org/10.1115/1.4032470
- Ballo, F, Gobbi, M, Mastinu, G, Previati, G, & Zerboni, R. "Motorcycle Tire Modeling." *Proceedings of the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 3: 17th International Conference on Advanced Vehicle Technologies; 12th International Conference on Design Education; 8th Frontiers in Biomedical Devices*. Boston, Massachusetts, USA. August 2–5, 2015. V003T01A030. ASME. https://doi.org/10.1115/DETC2015-46607

Simulators

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- Westerhof, B. E., De Vries, E. J. H., Happee, R., & Schwab, A. (2020, January). Evaluation of a motorcycle simulator. Symposium on the Dynamics and Control of Single Track Vehicles.

SMART WHEEL

Gobbi, M., Mastinu, G., Ballo, F., and Previati, G.,
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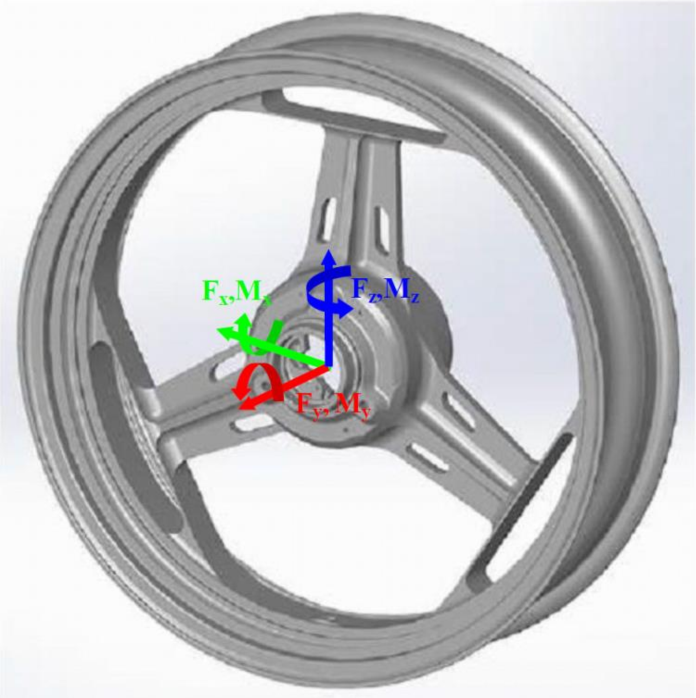
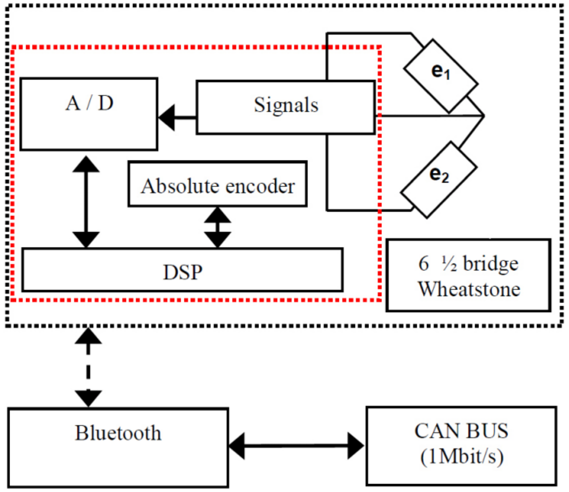
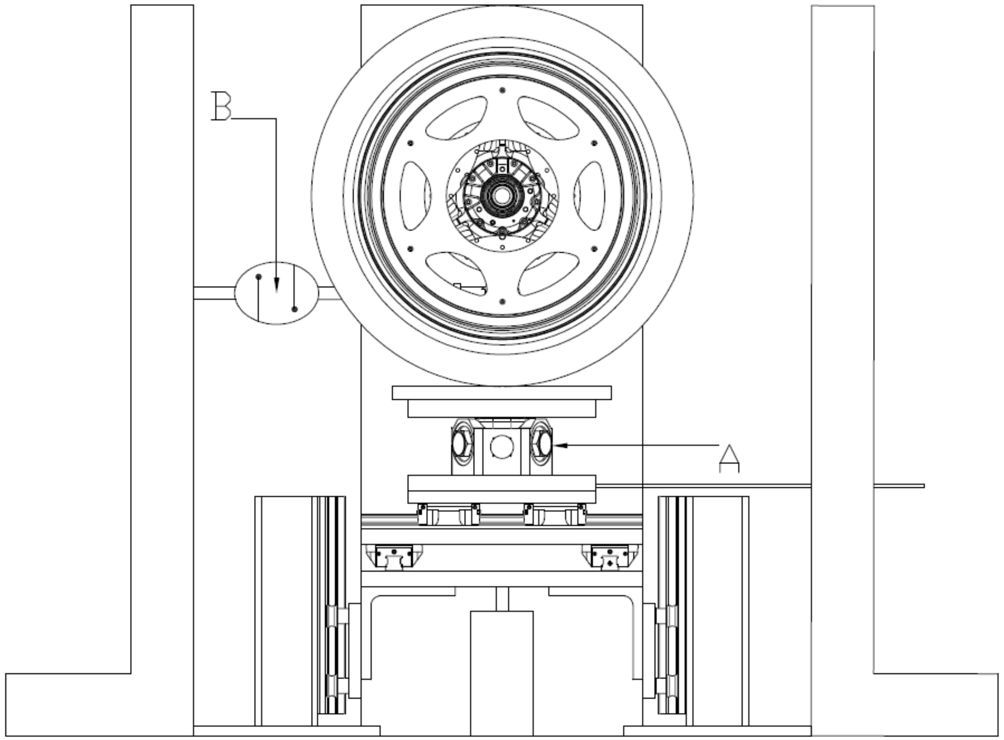
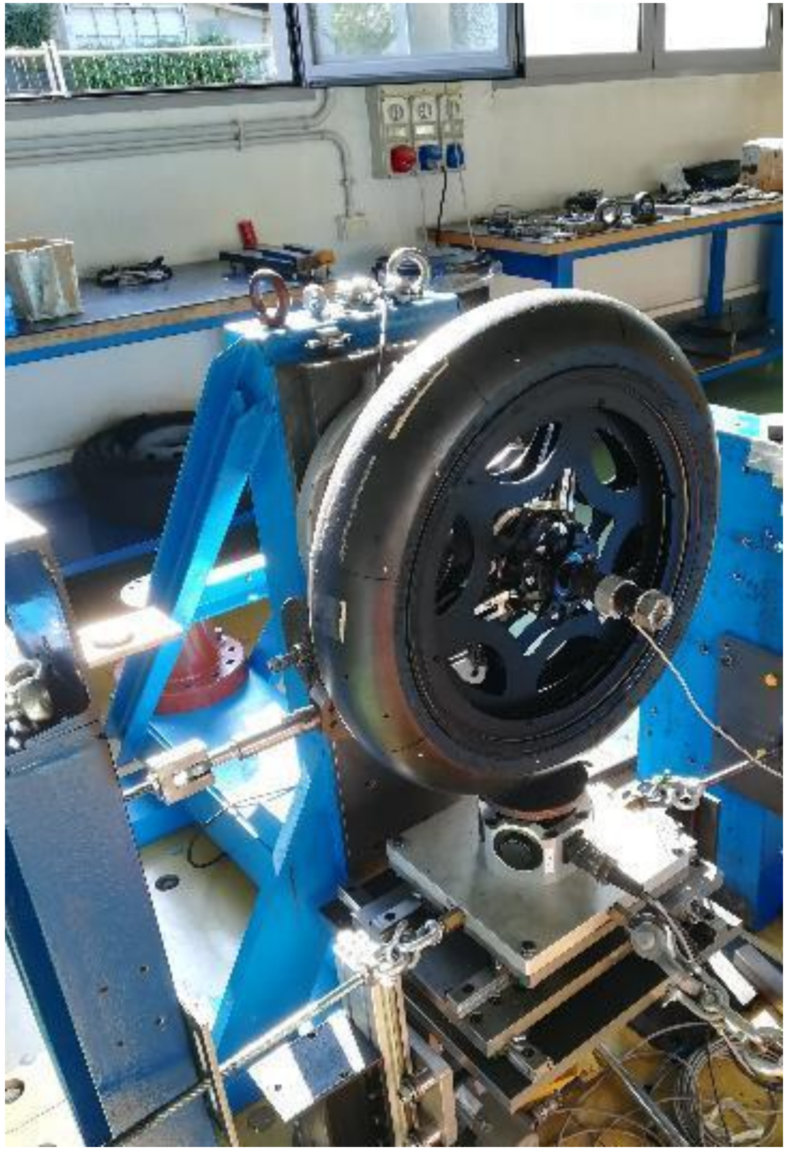
SAE Int. J. Passeng. Cars - Mech. Syst. 8(1):119-127, 2015,
https://doi.org/10.4271/2015-01-1520.





SMART WHEEL CALIBRATION





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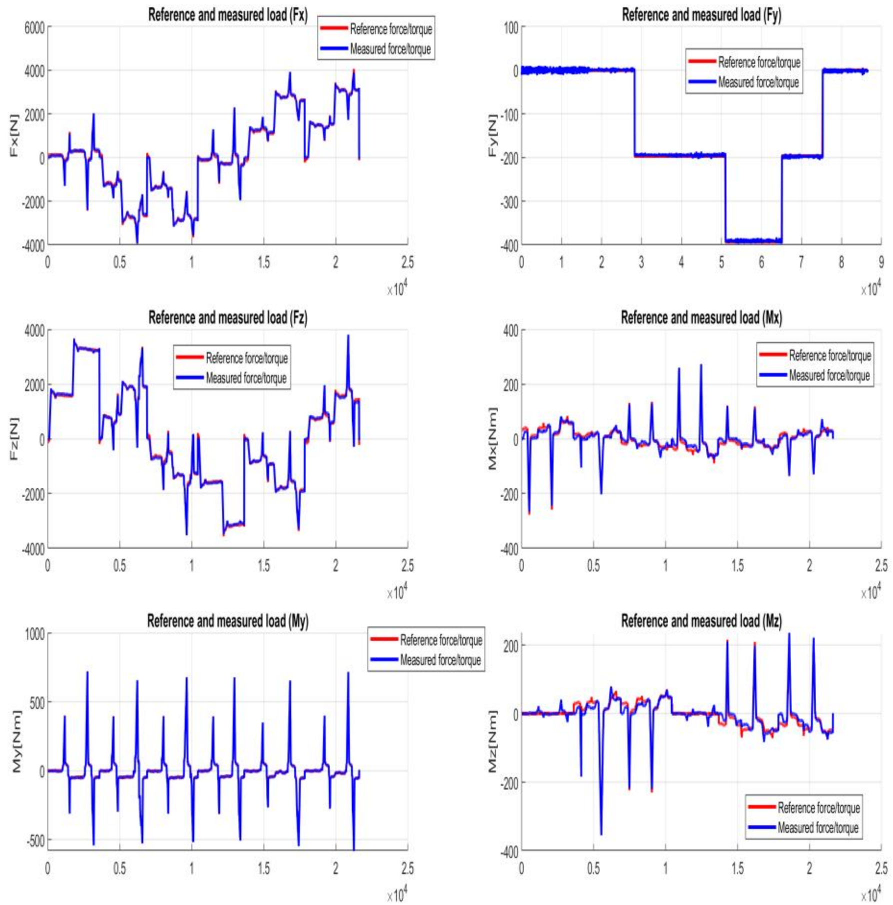
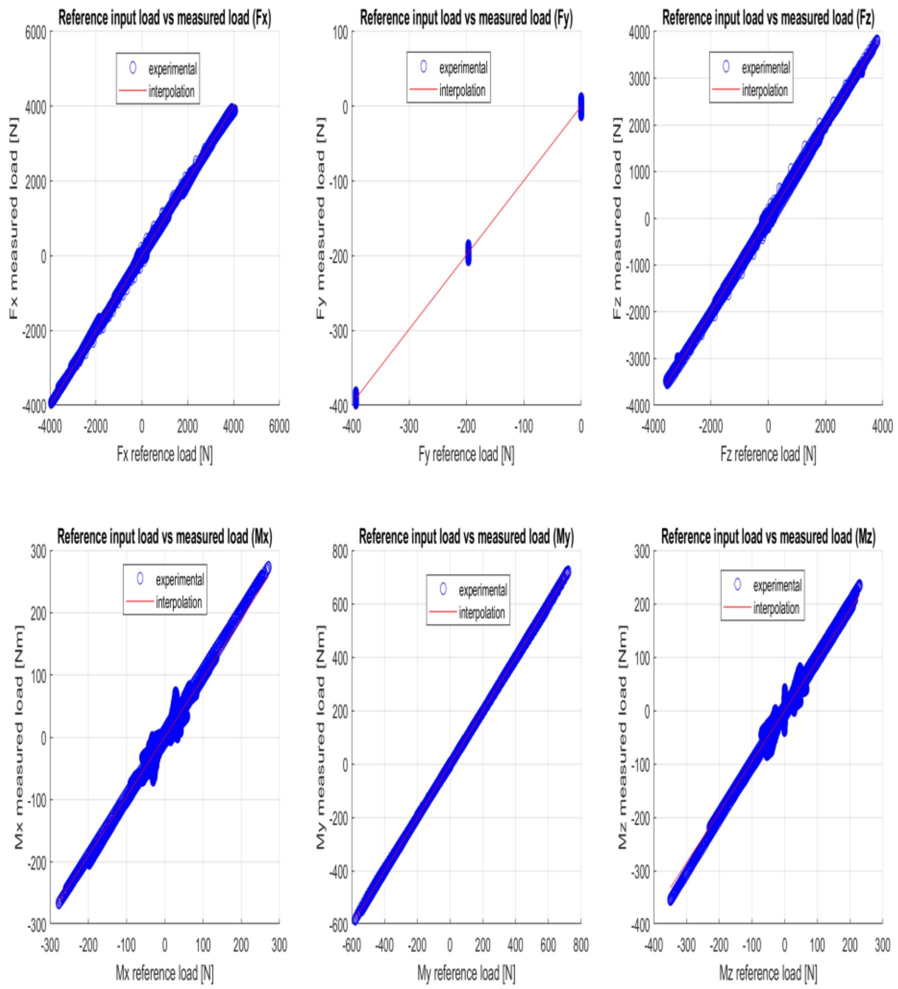
SMART WHEEL CALIBRATION





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SMART WHEEL PERFORMANCE

Value	Accuracy [%]	Max load	Confidence	Accuracy		Calibration load
Fx [N]	+/- 1,5%	4500	+/- 2σ	+/- 67,5		+/- 4000
Fy [N]	+/- 0,5%	1000	+/- 2σ	+/- 5		- 400
Fz [N]	+/- 1,5%	4500	+/- 2σ	+/- 67,5		+/- 4000
Mx [Nm]	+/- 1,5%	500	+/- 2σ	+/- 7,5		+/- 300
My [Nm]	+/- 0,5%	3000	+/- 2σ	+/- 15		+/- 800
Mz [Nm]	+/- 1,5%	500	+/- 2σ	+/- 7,5		+/- 300

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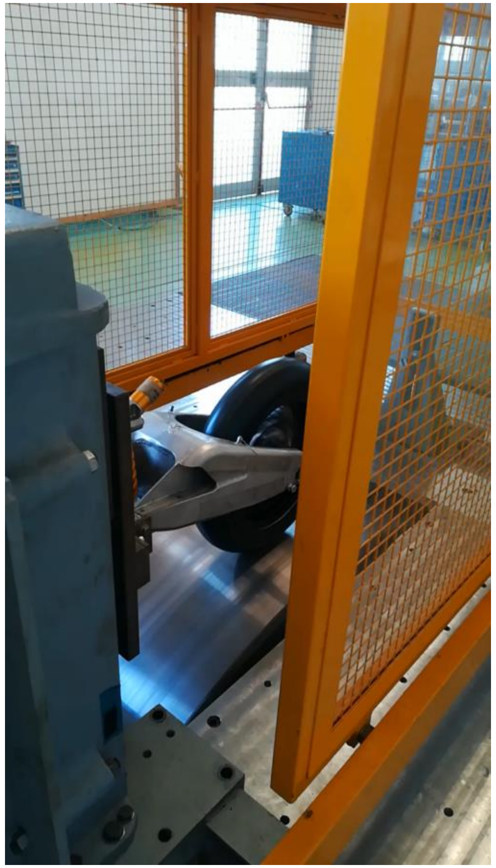
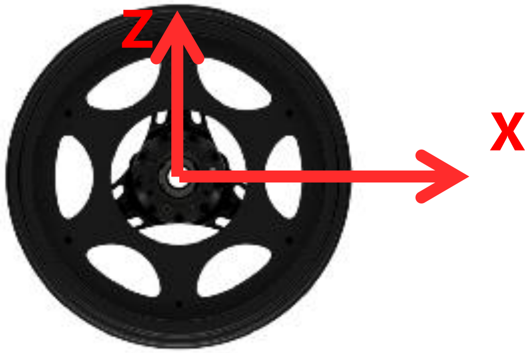
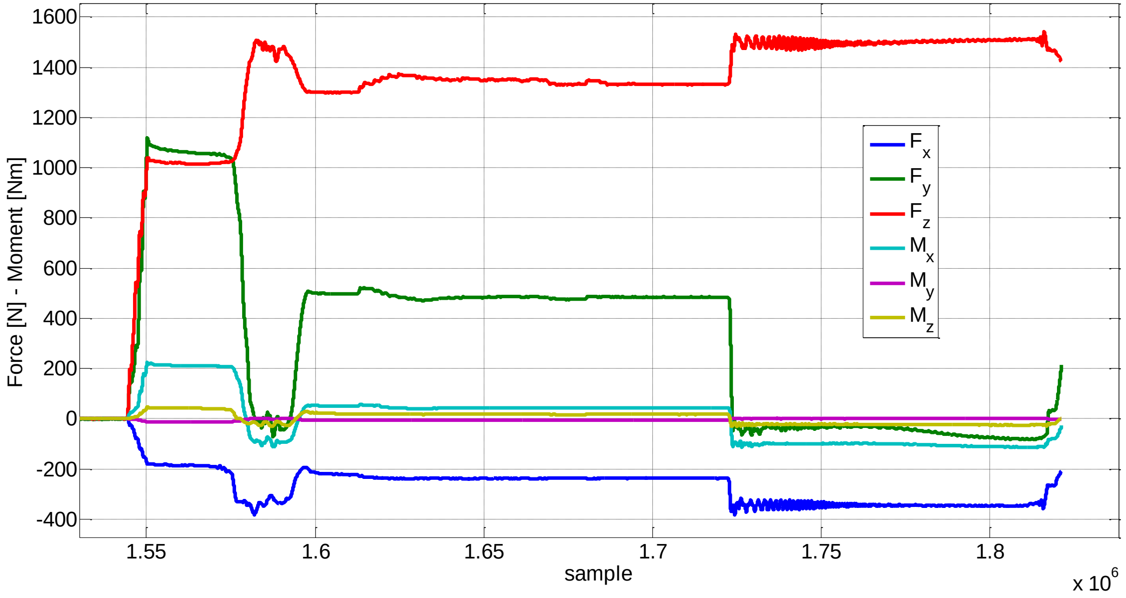
SMART WHEEL – HIGH SPEED TESTING







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SMART WHEEL – TRACK

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CONCLUSION

Dynamic behavior of motorcycles depend mainly on the inertia properties of the vehicle and on the tire characteristics.

Accuracy required for tyre forces measurement is <2% on both forces and moments.
Accuracy required on inertia tensor components is <2% for MOI and <1% for POI.
Intensino+ and SM_SmartWheel provide the required accuracy level.

A 10% variation of the inertia parameter values significant variations can be observed both on the tracking errors and on the utilization of the control motors.

Both these information (inertia properties and tyre characteristics) play a fundamental role in providing the "reality feel" to driving simulator users.

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