The Full Autonomous Racing Car of UniNa Corse: Design and Validation

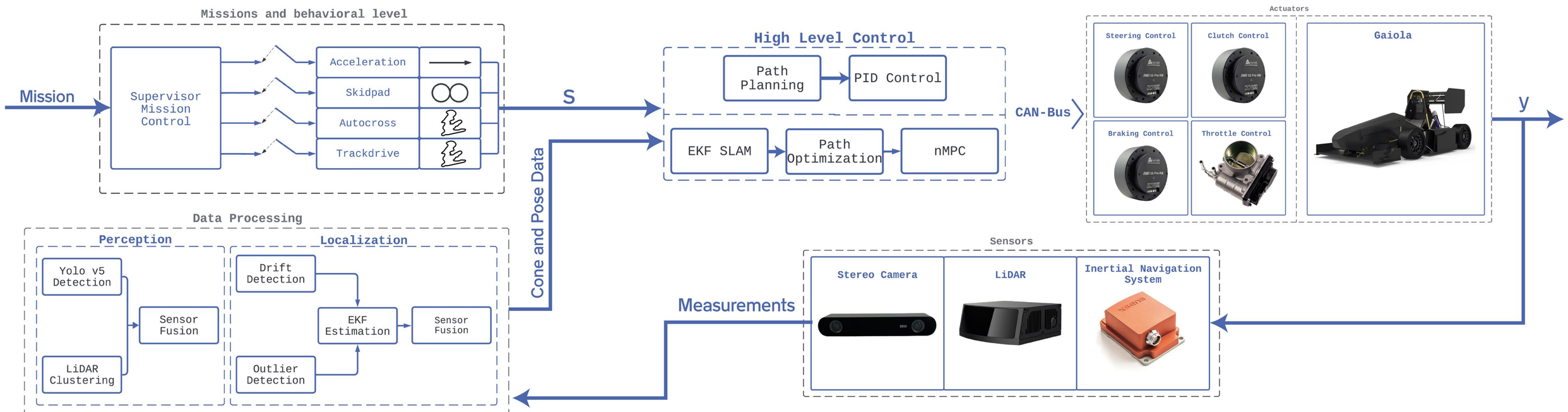
Francesco Conversano[1], Giovanni Marciello[1], Aniello Mungiello[1], Alberto Petrillo[1], Stefania Santini[1]

1 University of Naples Federico II, (f.conversano, gi.marciello, aniello.mungiello, alberto.petrillo, stefania.santini)@unina.it

www.daisylab.dieti.unina.it

UniNa Corse is the racing team of the University of Naples Federico II.
Born in 2010 from the common intention of professors and students to create a project that would allow the latter to apply what they have studied in their courses of study, in a highly diverse competitive educational environment, with the final objective of **designing, producing and testing a competitive single-seater** that would compete in the globally acknowledged formula student competition.

AUTONOMOUS SYSTEM PIPELINE



SENSOR FUSION & FAULT DETECTION

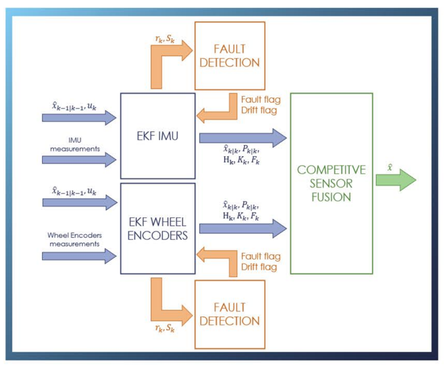
$$P_{ij}(t,t) = [I - K_i(t)H_i]\left[F_i P_{ij}(t-1,t-1)F_j^T + \Gamma Q(t-1)\Gamma^{\mathrm{T}}\right]\left[\mathrm{I} - \mathrm{K_j(t)H_j}\right]^{\mathrm{T}}$$ **Cross Covariance**

$$\begin{cases} \bar{\alpha} = [\overline{\alpha_1}, \overline{\alpha_2} \dots, \overline{\alpha_n}] \\ \bar{\alpha} = \dfrac{\Phi^{-1} I}{I^T \Phi^{-1} I} \\ \Phi = \begin{pmatrix} tr(P_{11}) & \cdots & tr(P_{1j}) \\ \vdots & \ddots & \vdots \\ tr(P_{i1}) & \cdots & tr(P_{ij}) \end{pmatrix} \end{cases}$$ **Weight Coefficient**

$$\hat{x}(t) = \sum_{i=1}^{n} \overline{\alpha_i} \cdot \hat{x_i}$$ **Optimal Multi-Sensor Fusion**

$$r^T S^{-1} r < \chi^2(0.95)$$ **Chi Squared Outlier Detection**

$$\sum_{i=1}^{n} (z_i - \mu_z)^2 < k$$ **Sensor Drift Detection**



r ⟷ Residual of innovation
z_i ⟷ Sensor measurement

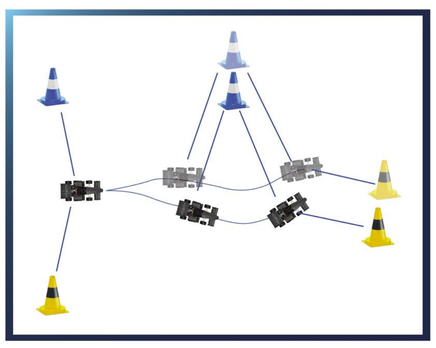
EKF LOCALIZATION AND MAPPING

$$\mu = [x, y, \psi, l_{1x}, l_{1y}, \dots, l_{nx}, l_{ny}]$$ **State Vector**

$$\begin{cases} l_{ix} = \overline{\mu_x} + R\cos(\theta + \overline{\mu_\psi}) \\ l_{iy} = \overline{\mu_y} + R\sin(\theta + \overline{\mu_\psi}) \end{cases}$$ **Cones Initialization**

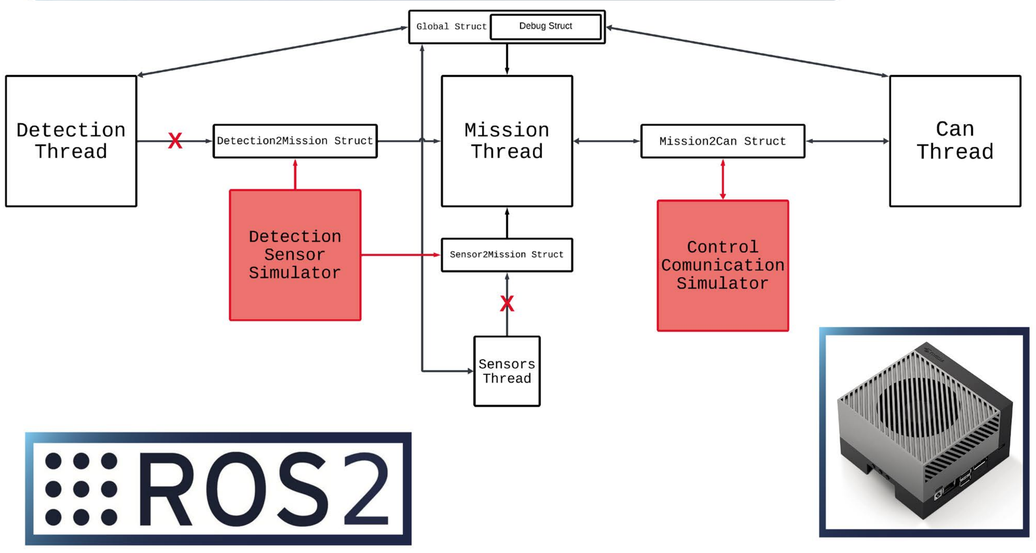
$$h(\overline{\mu_t}) = \begin{bmatrix} \sqrt{(l_x - \overline{\mu_x})^2 + (l_y - \overline{\mu_y})^2} \\ \tan^{-1}\left(\dfrac{l_y - \overline{\mu_y}}{l_x - \overline{\mu_x}}\right) - \overline{\mu_\psi} \\ \overline{\mu_\psi} + T_s \dot{\overline{\mu_\psi}} \end{bmatrix}$$ **Expected Measures**

$$\mu_t = \overline{\mu_t} + K z_t$$ **State Update**



R ⟷ Range
θ ⟷ Bearing
T_s ⟷ Sample Time

HARDWARE IN THE LOOP IMPLEMENTATION

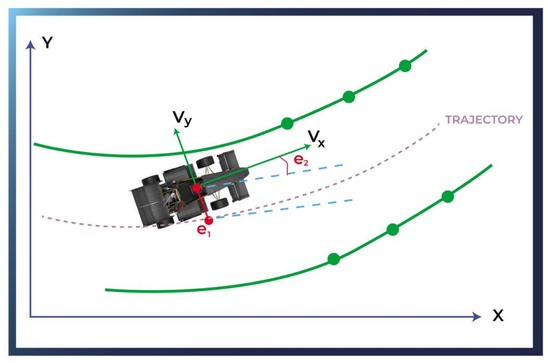


NON-LINEAR MODEL PREDICTIVE CONTROL

$$min \sum_{k=0}^{N-1} \|y_i(t+k|t)\|_Q^2 + \|u_i(t+k|t)\|_W^2$$

$$x_{k+1} = f(x_k, u_k)$$
$$y_k = g(x_k)$$ **State prediction of the vehicle system to control**

$$x_{min} \le x_k \le x_{max}$$
$$u_{min} \le u_k \le u_{max}$$
$$\Delta u_{min} \le \Delta u_k \le \Delta u_{ma}$$
$$y_{min} \le y_k \le y_{max}$$ **System constraints**



$$J(z_k) = J_y(z_k) + J_u(z_k) + J_{\Delta u}(z_k) + J_\varepsilon(z_k)$$ **Cost Function**

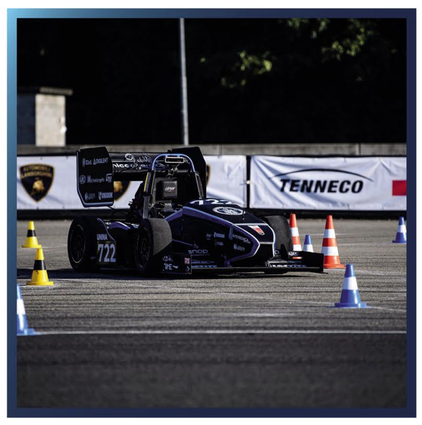
$$J_y(z_k) = \sum_{j=1}^{n_y} \sum_{i=1}^{p} \left\{ \frac{w_{i,j}{}^y}{s_j{}^y} [r_j(k+i|k) - y_j(k+i|k)] \right\}^2$$ **Output Reference Tracking**

$$J_u(z_k) = \sum_{j=1}^{n_u} \sum_{i=0}^{p-1} \left\{ \frac{w_{i,j}{}^u}{s_j{}^u} [u_j(k+i|k) - u_{j,target}(k+i|k)] \right\}^2$$ **Manipulated Variable Tracking**

$$J_{\Delta u}(z_k) = \sum_{j=1}^{n_u} \sum_{i=0}^{p-1} \left\{ \frac{w_{i,j}{}^{\Delta u}}{s_j{}^u} [u_j(k+i|k) - u_j(k+i-1|k)] \right\}^2$$ **Manipulated Variable Move Suppression**

$$J_\varepsilon(z_k) = \rho_\varepsilon \varepsilon_k{}^2$$ **Constraint Violation**

RACING VIBES



1 — formula ata

2 — FORMULA STUDENT CZECH REPUBLIC

5 — formula student