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Hugues Mounier, Sylvie le Hégarat, Roger Reynaud, Brigitte d'Andréa-Novel

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ComFuCet: Embedded and real-time control and fusion

ABSTRACT

Recent tools in nonlinear control and estimation appear especially well suited to the control of embedded and real-time systems. The main guidelines of the present project are outlined, as well as the main tools we shall use.

1 Goals and guidelines

The present project aims at developping control and fusion schemes that can adapt to varying environments. Considering an automotive case, the schemes should adapt to the scene complexity and to its supposed danger level. More precisely, one needs

1. A temporal adaptation, i.e. the evolution speed of the whole system should be adapted to the external context (e.g., for a car to be alone on a motorway or to be in a croudy street with many children) ; this is outlined in section 2.
2. To change behavior in a very fast manner ; this can be done by pre-computing several possible trajectories to be tracked, being able to commute from one to another at any time. This is presented in section 3.

To this aim, we shall use recent control theoretic tools that appear to be particularly well suited:

1. Differential flatness (in section 4) which enables to mix feedforward (based on physical models) and feedback, and is excellent for trajectory tracking.
2. Model free control (in section 5) which will be used, in conjunction to the previous, for poorly known parts of the system (such as, e.g., tyre/road contact forces).
3. Algebraic identification procedures (in section 6), which model free control uses heavily.

The proposed framework will greatly enhance system safety, and aims to be embedded, as the ones of Figure 1.

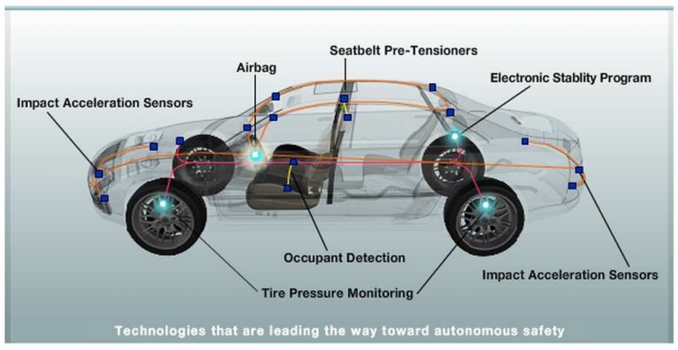

Figure 1. Current car safety functions.

2 Variable trajectory tracking speed

A clock control enables to vary the speed with which the trajectories are being tracked. More precisely, the $\boldsymbol{\omega}(t)$ in (2) used in (3) is replaced with $\boldsymbol{\omega}(\alpha t)$ with a time varying α, acting as a clock control. The bigger α is, the slower the trajectories are being pursued.
Hence, according to the environment complexity and its danger index, the clock control will be used to slow down or accelerate the tracking speed.

3 Temporal horizon hierarchy

Several temporal ranges are considered: short term ones, within a second; mid term ones, within 10 second; and long term ones, within a minute and above. Several associated objectives reflect the growing semantic complexity:

1. Tracking a single trajectory in the short term
2. Evolving in a trajectory sheaf in the mid term
3. Deciding among a sheaf of sheaves in the long term

In 1 a stabilizing tracking scheme shall be used, using differential flatness and model free control. In 2, switching from an element of the sheaf to another is allowed, according to appropiate decision criteria. Examples of such criteria for an automotive setting may be found in [4].

4 Differentially flat systems [2]

Definition. The system

$$\dot{\boldsymbol{x}} = f(\boldsymbol{x}, \boldsymbol{u}) \tag{1}$$

with $\boldsymbol{x} \in \boldsymbol{R}^n$ and $\boldsymbol{u} \in \boldsymbol{R}^m$ is differentially flat if there exists a so-called a flat output,

$$\boldsymbol{\omega} = h(\boldsymbol{x}, \boldsymbol{u}, \dot{\boldsymbol{u}}, \ldots, \boldsymbol{u}^{(r)}), \qquad \boldsymbol{\omega} \in \boldsymbol{R}^m, r \in \boldsymbol{N} \tag{2}$$

such that

$$\boldsymbol{x} = \boldsymbol{A}(\boldsymbol{\omega}, \dot{\boldsymbol{\omega}}, \ldots, \boldsymbol{\omega}^{(\rho_x)}), \quad \boldsymbol{u} = \boldsymbol{B}(\boldsymbol{\omega}, \dot{\boldsymbol{\omega}}, \ldots, \boldsymbol{\omega}^{(\rho_u)}) \tag{3}$$

with q an integer, and such that the following are identically satisfied:

$$\frac{dA}{dt}(\boldsymbol{\omega}, \dot{\boldsymbol{\omega}}, \ldots, \boldsymbol{\omega}^{(q+1)}) = f(A(\boldsymbol{\omega}, \dot{\boldsymbol{\omega}}, \ldots, \boldsymbol{\omega}^{(q)}), B(\boldsymbol{\omega}, \dot{\boldsymbol{\omega}}, \ldots, \boldsymbol{\omega}^{(q+1)}))$$

Example. Let us recall the kinematic model of a car:

$$\dot{x}(t) = v(t)\cos\psi(t) \tag{4a}$$
$$\dot{y}(t) = v(t)\sin\psi(t) \tag{4b}$$
$$\dot{\psi}(t) = v(t)\frac{\tan\delta(t)}{L} \tag{4c}$$

Where the controls are the propulsion speed $v(t)$ and the steering angle $\delta(t)$.
The kinematic model (4) is flat with (x, y) as a flat output. Indeed, (4a)^2+ (4b)^2 and (4b)/(4a) respectively lead to $v = \sqrt{\dot{x}^2 + \dot{y}^2}$, and $\psi = \mathrm{Atan}(\dot{y}/\dot{x})$ And (4c) yields $\dot{\psi}$. Finally, one has

$$v = \sqrt{\dot{x}^2 + \dot{y}^2}, \quad \psi = \mathrm{Atan}\left(\frac{\dot{y}}{\dot{x}}\right), \quad \delta = \mathrm{Atan}\left(L\frac{\ddot{y}\dot{x} - \dot{y}\ddot{x}}{(\dot{x}^2 + \dot{y}^2)^{3/2}}\right) \tag{5}$$

5 Model free control [1]

A general nonlinear system with measure z and control u is modelled by:

$$z_1^{(n)} = F + \alpha u \tag{6}$$

where F is an unknown (and/or unmodelled) term, and α is a constant. The latter is chosen so that F and αu are of comparable magnitude.
The estimate $\tilde{F}$ of F is obtained through the following which avoids any algebraic loop:

$$\tilde{F}(t_k) = \left[z^{(n)}(t_k)\right]_e - u(t_k - 1) \tag{7}$$

where $\left[\bullet(t_k)\right]_e$ designates the estimate at the sampled time t_k.
The choice of the reference trajectory z^* of z is done as is usually done in flatness based control. If $n = 1$, the chosen control is a so-called intelligent PI or i-PI:

$$u = -\frac{\tilde{F}}{\alpha} + \frac{\dot{z}^*}{\alpha} + k_p(z - z^*) + k_i \int (z - z^*) \tag{8}$$

Advantages: No need for any identification procedure; the reference trajectories may be freely chosen, thus avoiding classical overshoots and oscillations.

6 Algebraic estimation [3]

Suppose we want to estimate the derivative of a signal $z(t)$. Taking a first order polynomial model : $z(t) = a_0 + a_1 t$, wich reads in operational domain: $Z(s) = a_0/s + a_1/s^2$. We apply the following transformations: Multiplication by s, differentiation wrt s, and multiplication by s^{-2} (filtering) yields, in the temporal domain:

$$\hat{a}_1 = -\frac{3!}{T^3}\int_0^T (T - 2\tau)y(\tau)\,d\tau$$

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Contacts: Hugues.Mounier@u-psud.fr · Sylvie.Le-Hegarat@u-psud.fr · Roger.Reynaud@u-psud.fr

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