Effective Vehicle Sideslip Angle Estimation using DVS Technology

M. Milanese, Modelway srl

I. Gerlero, Modelway srl

C. Novara, Politecnico di Torino

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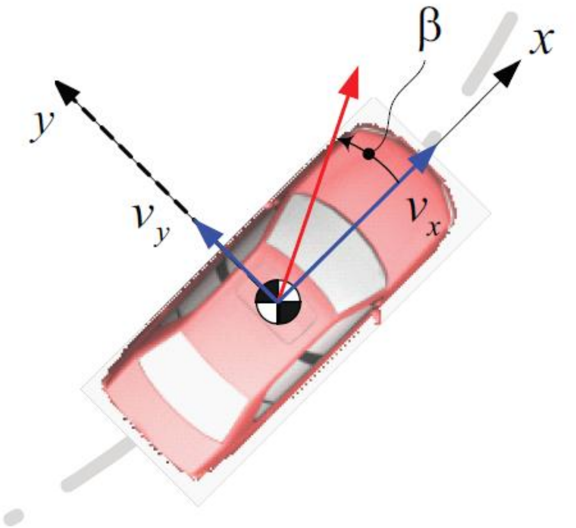
Introduction

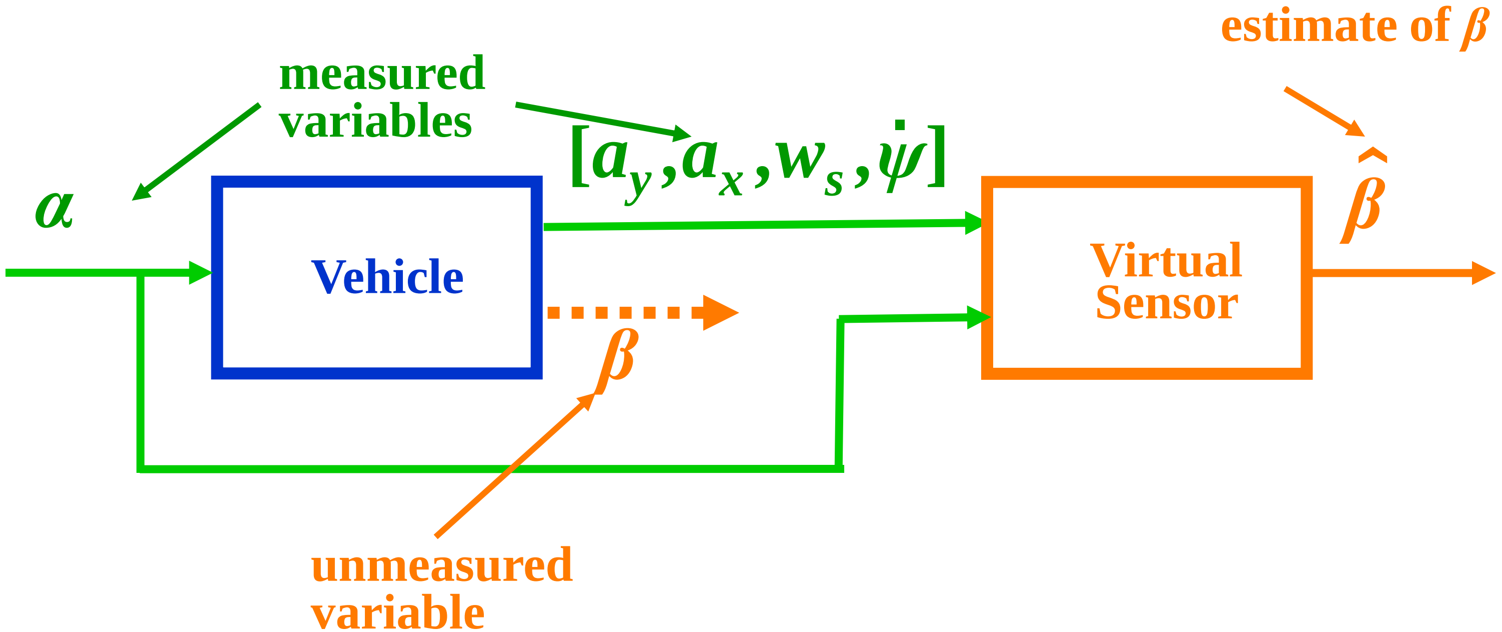
- **Sideslip angle *β* is a most relevant variable in vehicle dynamics**
- **Its knowledge may allow significant improvements over standard ESC systems based on yaw rate control**



- **Direct measurement of *β* requires the use of optical or inertial+GPS devices which cannot be used in production cars**

Introduction

- **The estimation of *β* based on signals measured from standard ESC sensors (steering angle, wheel velocities, yaw rate, lateral acceleration,…) has been intensively investigated, leading to software algorithms here called Virtual Sensor (VS)**

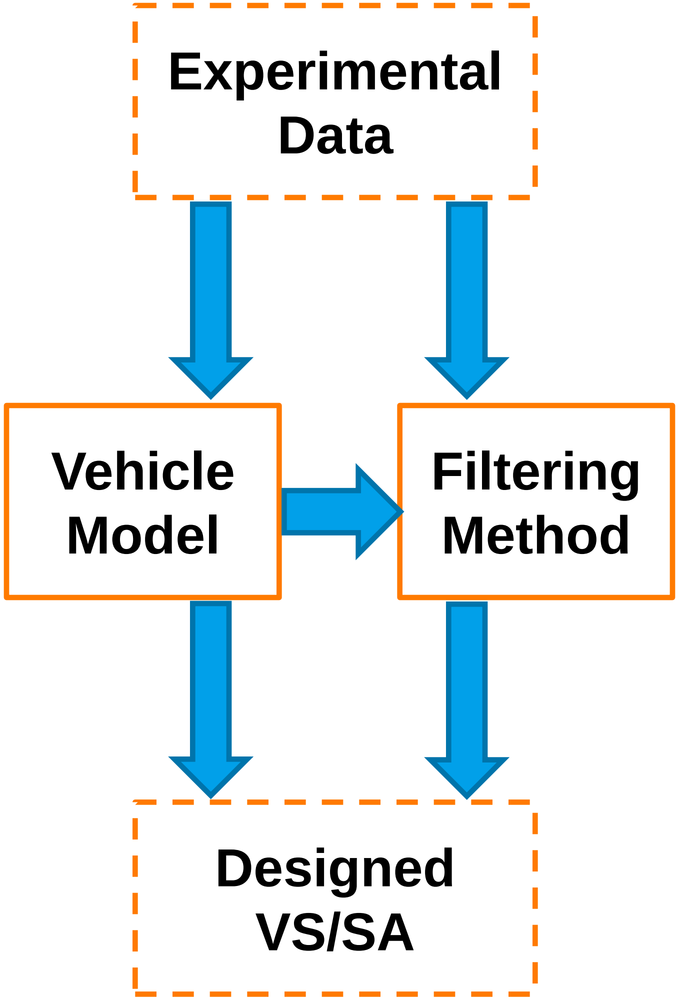


Two Step VS design

- All these investigations are based on a Two Step VS design procedure

- Existing filtering methods, operating on suitable vehicle models, are used for *β* estimation

- The filter and model parameters are tuned on the base of experimental data measured on a testing vehicle



Two Step VS design

- **Main open issues of Two Step design:**
  - **optimal estimation is computationally intractable and approximate solutions have to be used (e.g. EKF), whose accuracy is hardly evaluable**
  - **robustness of VS/SA performances vs. variations of car operational conditions (dry/wet road, tire status, car load,..) is very difficult to be achieved**

- **At the best of our knowledge, acceptable accuracy and robustness features has not yet been achieved by such methods, as suggested by the fact that, no application to production cars is known**

DVS technology

- Here, a new VS design technology is adopted for *β* estimation, indicated as DVS, which overcomes the open issues of Two Step VS design

- DVS[1] is based on the innovative observer/filtering methodology recently developed by the authors:

  Novara-Ruiz-Milanese, "Direct Filtering: A New Approach to Optimal Filter Design for Nonlinear Systems", IEEE Trans. on Automatic Control, 2013

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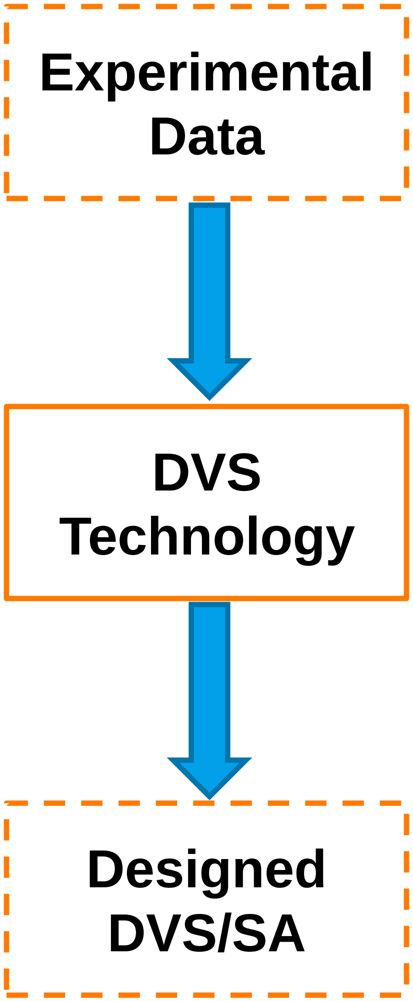
1. DVS®, Direct Virtual Sensor, registered trademark of Modelway

DVS technology

- DVS technology directly design the VS from the experimental data measured on a testing vehicle

- The identification of vehicle model is avoided



DVS technology

- **DVS technology main features:**
  - **optimal estimation is computationally tractable for the general non linear case**
  - **robustness features are directly obtained using experimental data related to the different operating conditions of interest (e.g. dry/wet road, tire status,…)**

DVS/SA design

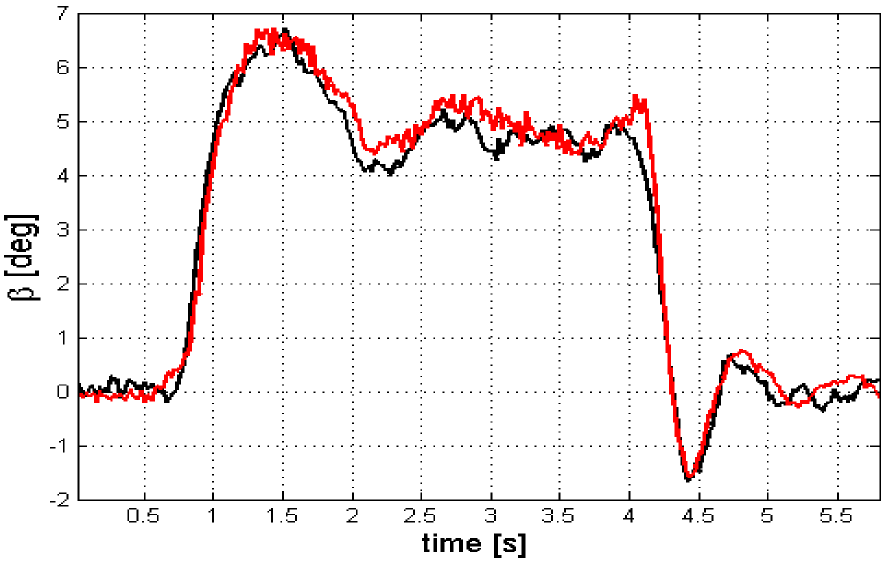
- **A DVS/SA has been designed for a segment D car**
- **A set of measurement has been performed on a testing car, in the following maneuvers:**
  - **Steering Angle Steps (SAS), with speed in the range 60-120 km/h and steering angle in the range 30-90 deg.**
  - **Lane Changes (LC) with speed in the range 60-120 km/h.**
  - **Curved Tracks (CT) performed on wet road and dry road, at speed up to 200 km/h**

DVS/SA design

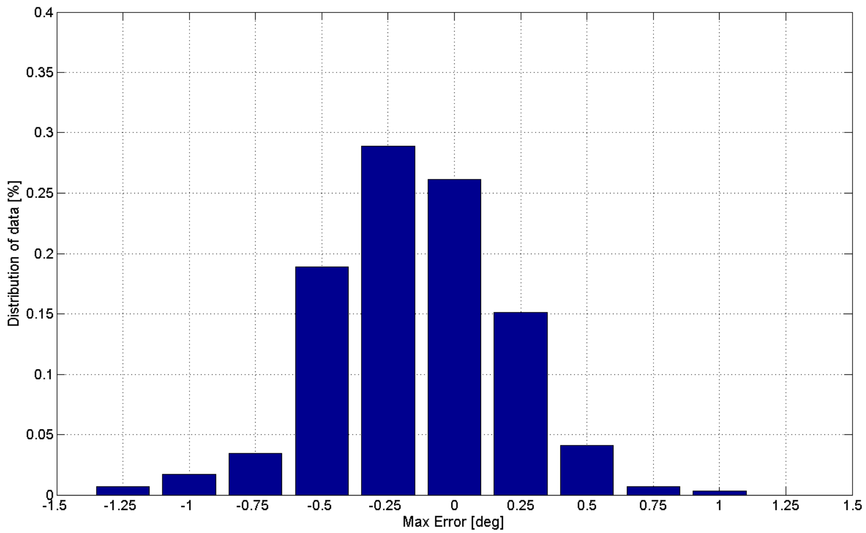
- **The measurements of $[\alpha, a_y, a_x, w_s, \dot{\psi}]$ values are acquired from the car ESC sensors**
- **The measurements of the *β* reference values have been acquired form a Correvit® optical sensor**
- **The sampling time for all signal acquisitions is 20 ms**
- **The designed DVS/SA performances have been evaluated on independent data sets. Some of them are presented below**

DVS/SA experiments results

SAS of 90 deg at speed of 100 km/h



Correvit® measure(Black); DVS\SA estimate (Red)



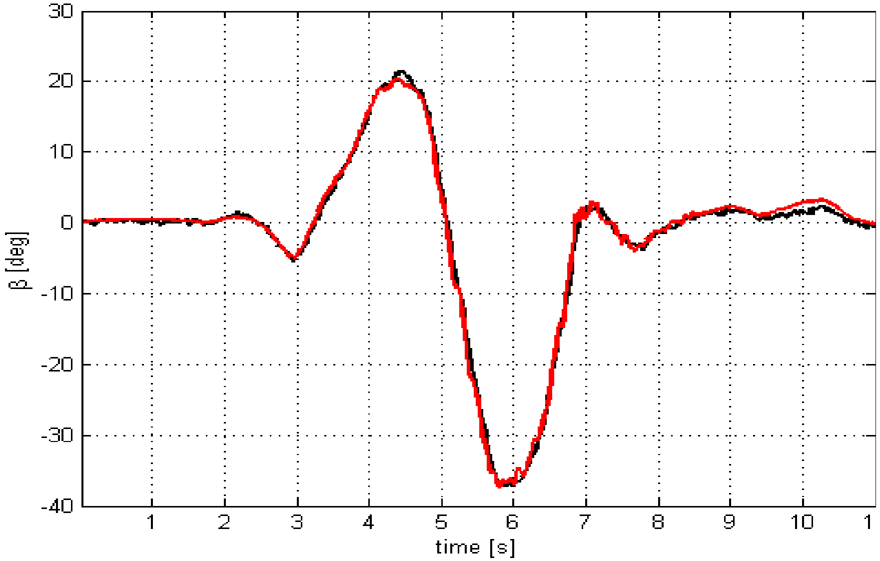
DVS/SA error distribution

Error performances:

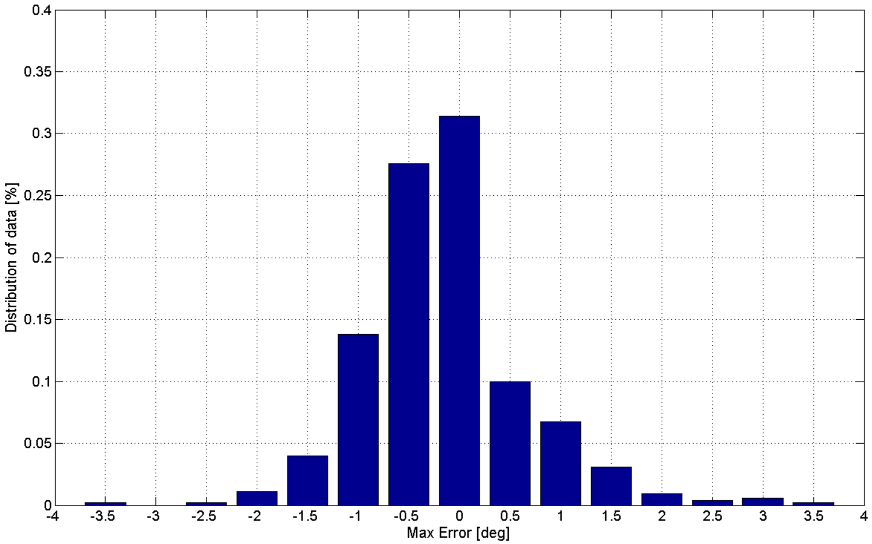
- mean = -0.14 deg
- std = 0.33 deg
- 90% confidence interval = 0.5 deg

DVS/SA experiments results

CT at speed of 115 Km/h on wet road



Correvit® measure(Black); DVS\SA estimate (Red)



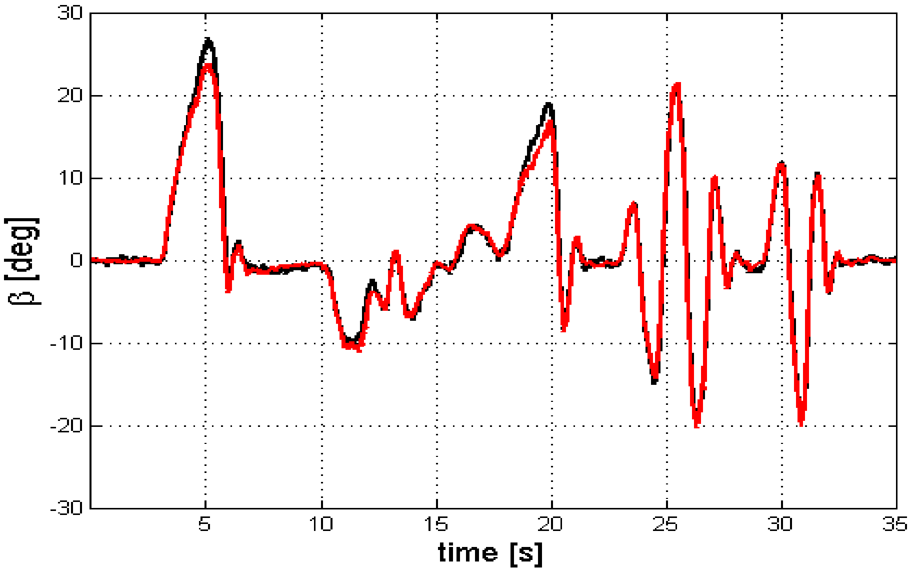
DVS/SA error distribution

Error performances:

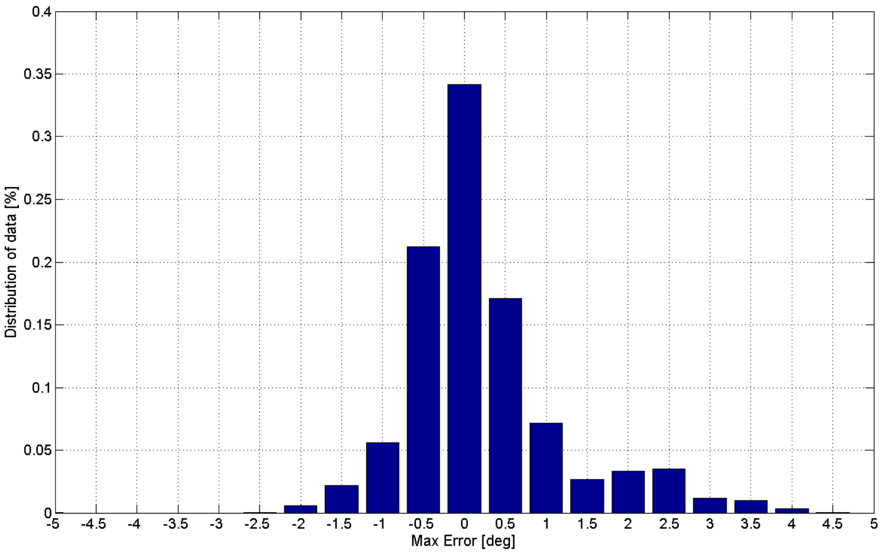
- mean = 0.22 deg
- std = 0.95 deg
- 90% confidence interval = 1.5 deg

DVS/SA experiments results

CT at speed of 200 Km/h on dry road



Correvit® measure(Black); DVS\SA estimate (Red)



DVS/SA error distribution

Error performances:

- mean = -0.15 deg
- std = 0.78 deg
- 90% confidence interval = 1 deg

DVS/SA: Conclusions

- **As major paper contribution, accuracy and robustness features of DVS technology are exploited for the vehicle sideslip angle estimation**
- **Experimental results are presented showing that the designed DVS/SA exhibits good estimation accuracy even for quite large operating condition variations**
- **DVS/SA has been recently made available on a top class car**

Thank you !

Contacts:

mario.milanese@modelway.it

ilario.gerlero@modelway.it

www.modelway.it