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First approach to wake vortex predicting and detecting integrated fusion filters

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Outline

- motivation/current situation
- state-of-the-art approaches
  - prediction models
  - measurement technologies
- collaboration approach
- excursus filter technologies
- conclusions

Wake vortices

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general motivation

Wake vortices as capacity limiting factors

- today: separation rules based on worst-case-scenario
  – assumed calm atmosphere, no lateral wind
    ➔ long wake vortex lifetime
- unnecessarily limiting capacities in favorable conditions
- **but:** separation reduction only possible while preserving safety level
- two approaches:
  – propagation of wake vortices by assessed models
  – detection and monitoring of wake vortices by dedicated sensors
  – operating quasi separately

Motivation for closer collaboration of model and sensor

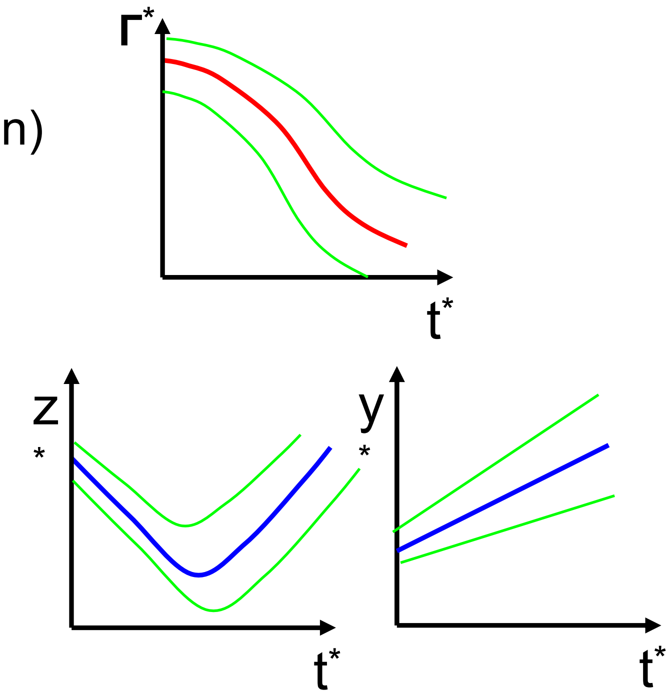
- benefit from using complementary characteristics for the operational (real-time) use
- allows the use of different measurement input sources, e.g. airborne sensor **AND** information coming from ground

  ➔ ground/board interaction
- close collaboration model / sensor at different scanning patterns
- allows observation of not-measured quantities through observability to some extent, e.g.
  - fast changing met-conditions
  - a/c-weight
  - a/c-speed
- helps decision making
- on-time reduction of model uncertainties through sensor measurements could result in capacity gain

The Propagation

State-of-the-art approaches - prediction

- propagation of wake vortex behaviour
- models: P2P (DLR), PVM (UCL), AVOSS-PA (NASA) proven in several projects
- real-time prediction of:
  - turbulence strength (circulation)
  - vortex trajectory in y and z
  - uncertainty bounds



Prediction model: input parameters

uncertainties

- aircraft configuration
  - weight, span, speed — unknown or varying
- weather conditions
  - wind profile
  - stratification
  - turbulence
  - wind shear

  lack of adequate spacial and temporal resolution; measurement and forecasting constraints
- ground proximity conditions

The Measurement

State-of-the-art approaches - detection

- wake vortex monitoring
  - measurement of wind velocities
  - focus on LIDAR (also X-band RADAR is a possibility)
  - research activities in several projects

- real-time measurement of:
  - turbulence strength (circulation)
  - vortex trajectory in y and z
  - range r and bearing θ of the sensor

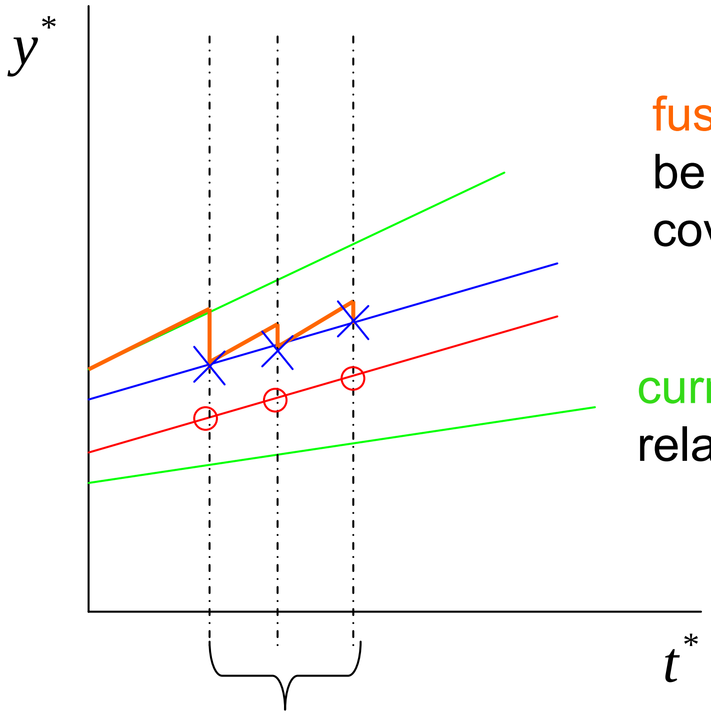
Complementary attributes of prediction and detection

Model	Sensor
good knowledge of vortex behaviour	limited field of view/difficulties in flow field identification
forecast ability	no information about vortex state between measurements or due to loss of track
short term stability	limited accuracy/noise
high prediction update rate	low measurement update rate
no real-time information update through measurement	physical wake detection
no update of changed meteorological conditions	updated information of vortex state
increasing uncertainty bounds due to model or met input uncertainties	decreased uncertainties on measurement update

➔ Typical example of two complementary systems

➔ Taking advantage by using only the positive characteristics of each system

Using complementary attributes



fused uncertainty bounds could be extracted from filters covariance

current uncertainty bounds relatively large

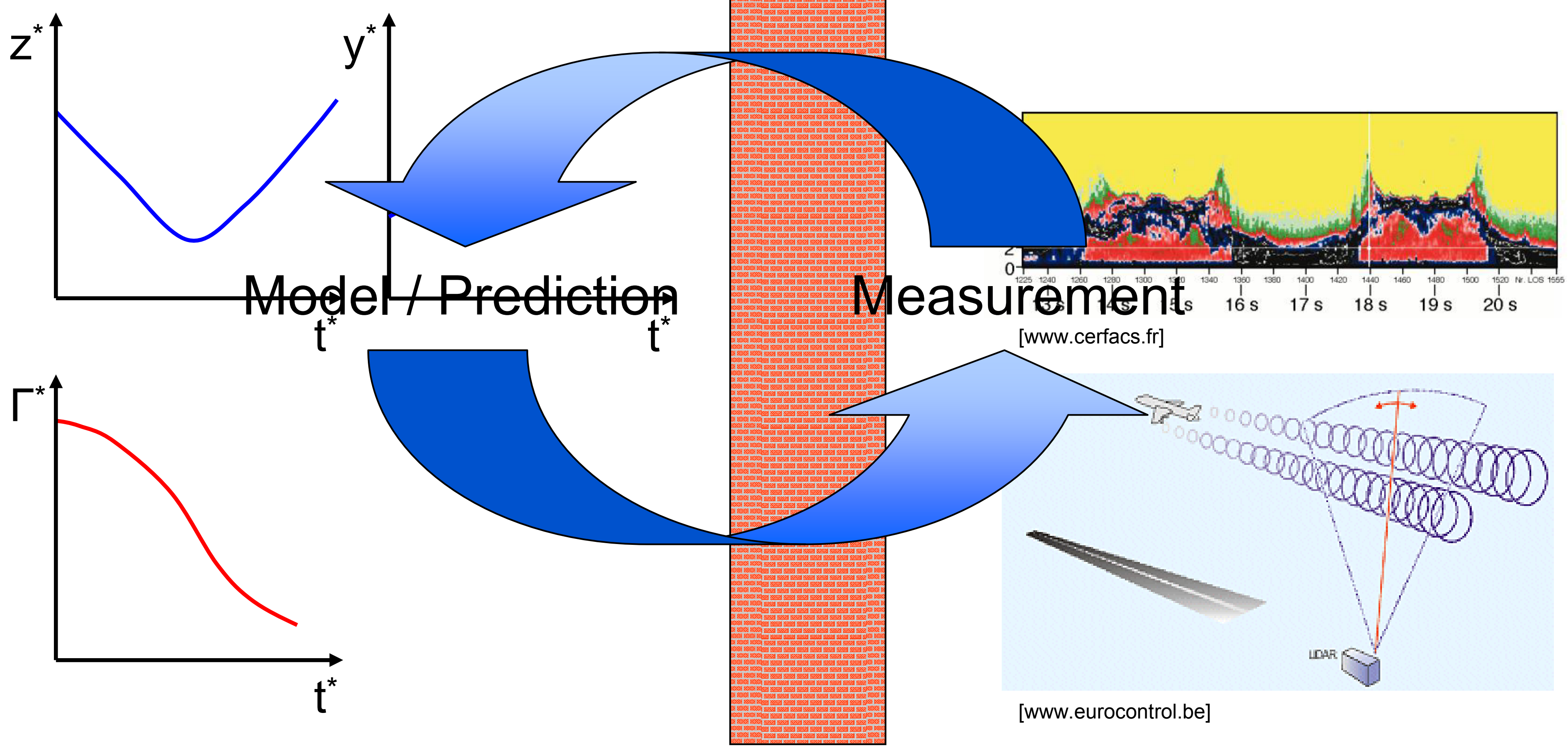
measurement-updates

Fusion filter concept
for
model / sensor collaboration

Collaboration approach

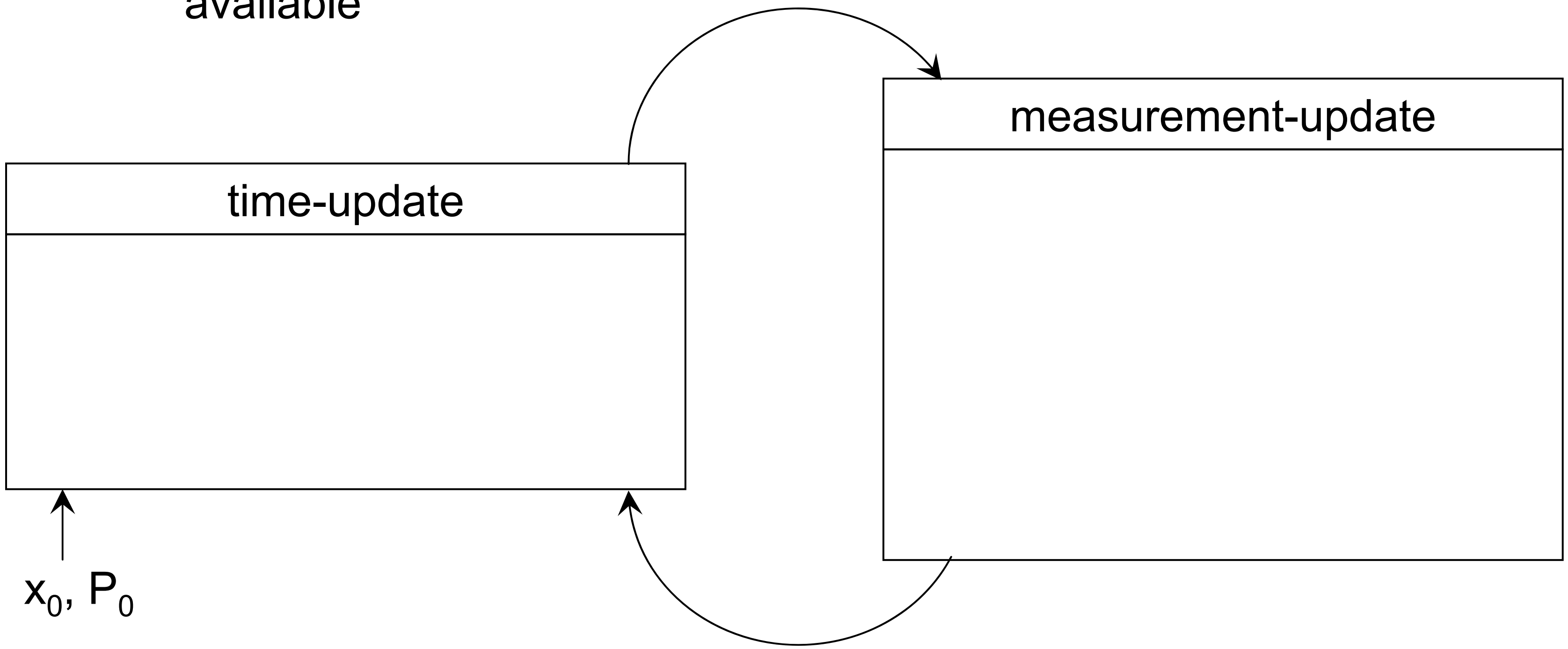
Model / Prediction

Measurement



Collaboration approach

- two steps:
  - a time update - system state is predicted based on current state
  - a measurement update - performed when new sensor data are available



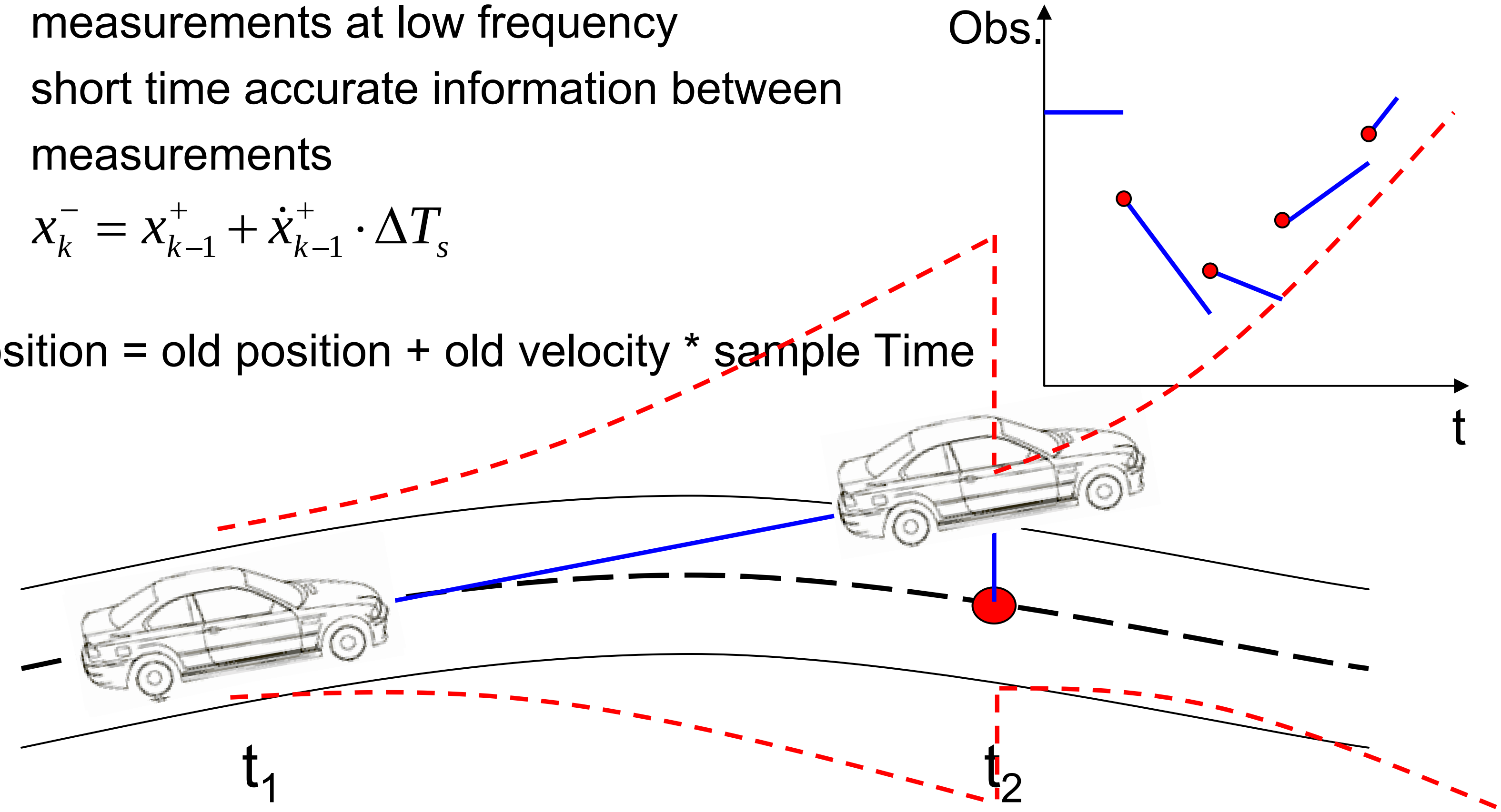
Some illustrating examples

Example with simplified model

- constant velocity
  - measurements at low frequency
  - short time accurate information between measurements

$$x_k^- = x_{k-1}^+ + \dot{x}_{k-1}^+ \cdot \Delta T_s$$

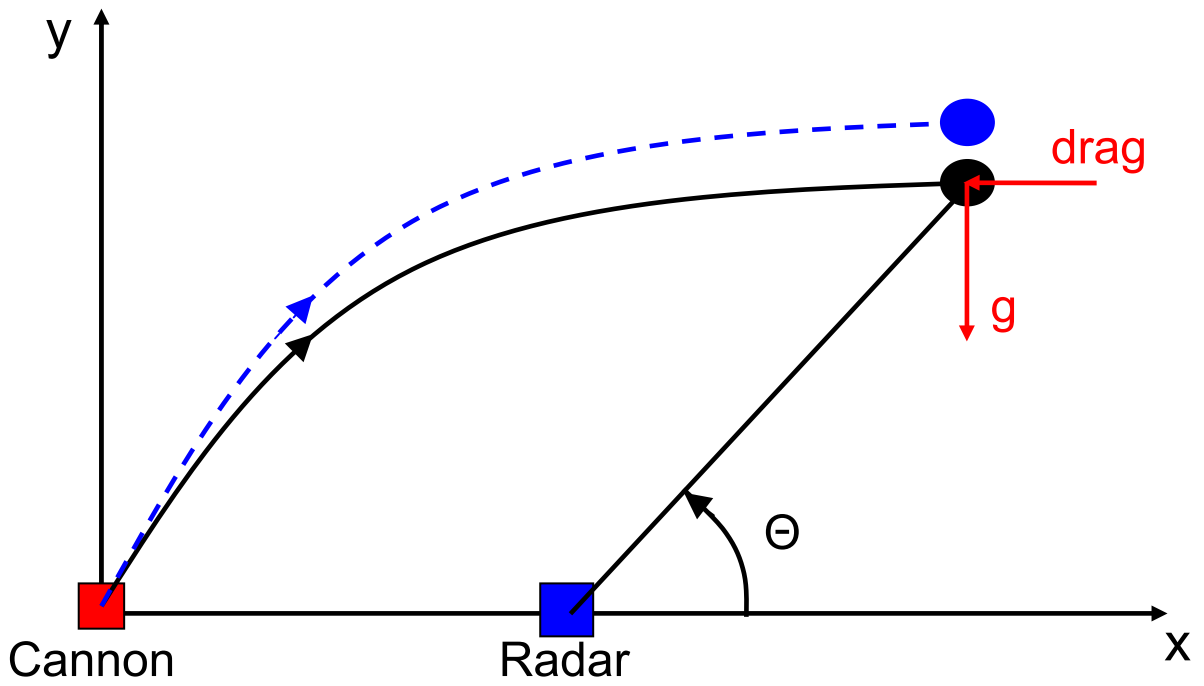
new position = old position + old velocity * sample Time



estimated Position corrected by difference model <> measurement

Example with specific model

- tracking object example: cannon-launched projectile tracking
  - model of movement exists (e.g. gravity, drag)
    ➔high frequent prediction
  - low frequent measurement updates model



Back

to

collaboration

Fusion Filter concept for collaboration

update on new prediction

time-update

state
WV traffic, MET, LIDAR-angles

model state transition
~ established prediction models

covariance
~ uncertainty bounds in current models, decreased by measurement

x_0, P_0

measurement-update

state
WV traffic, MET, LIDAR-angles

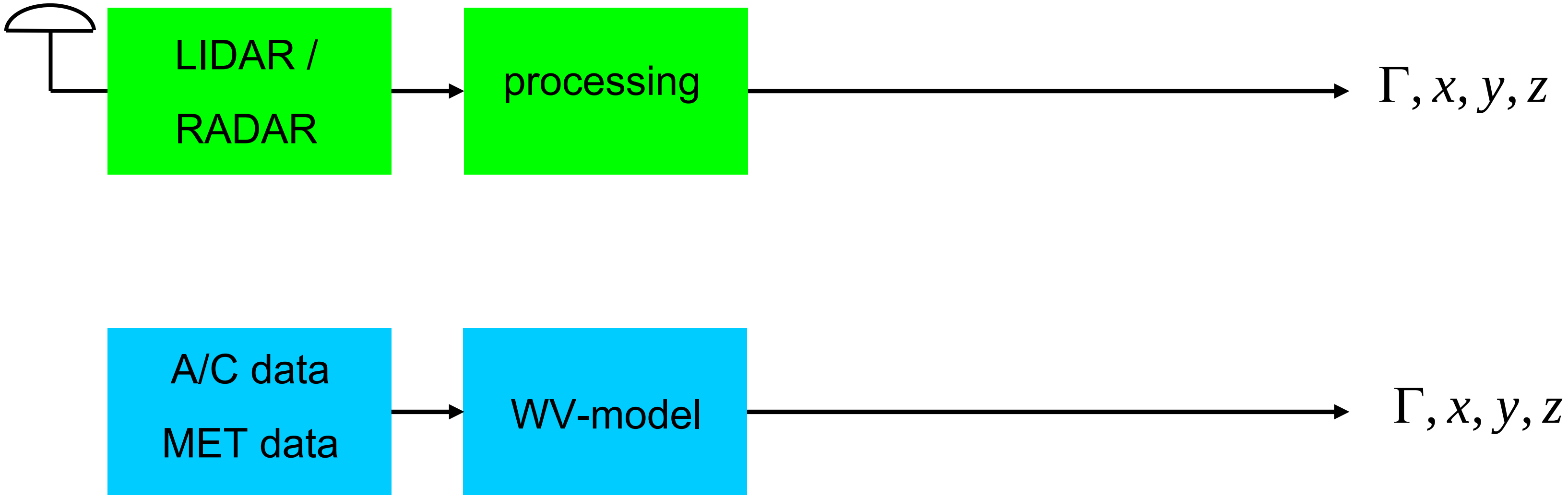
covariance
~ uncertainty bounds in current models, decreased by measurement

measured quantities
position, strength, range, bearing, TBD)

error/uncertainty-feedback

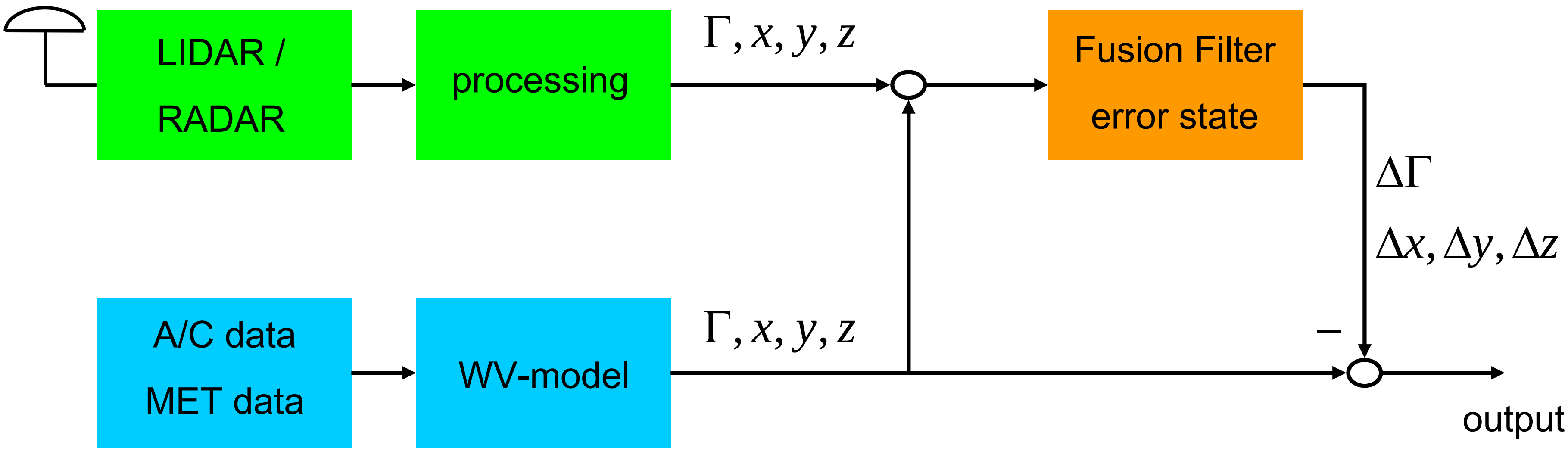
update on new measurement

Uncoupled



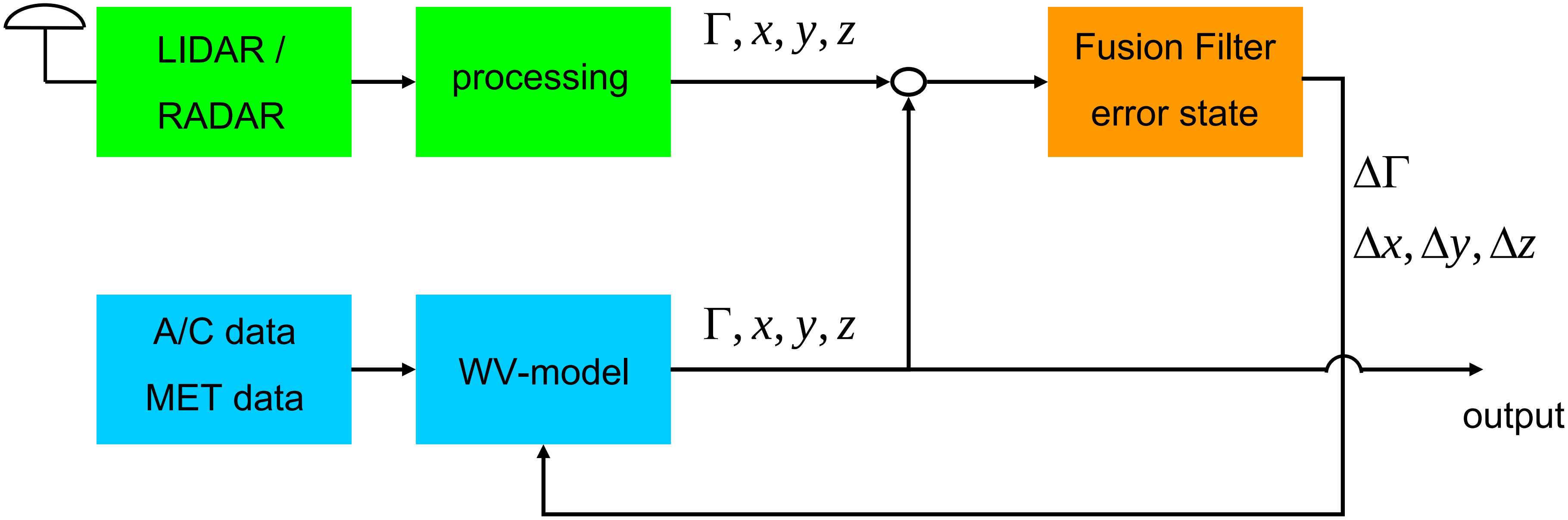
current status

Loose coupled approaches



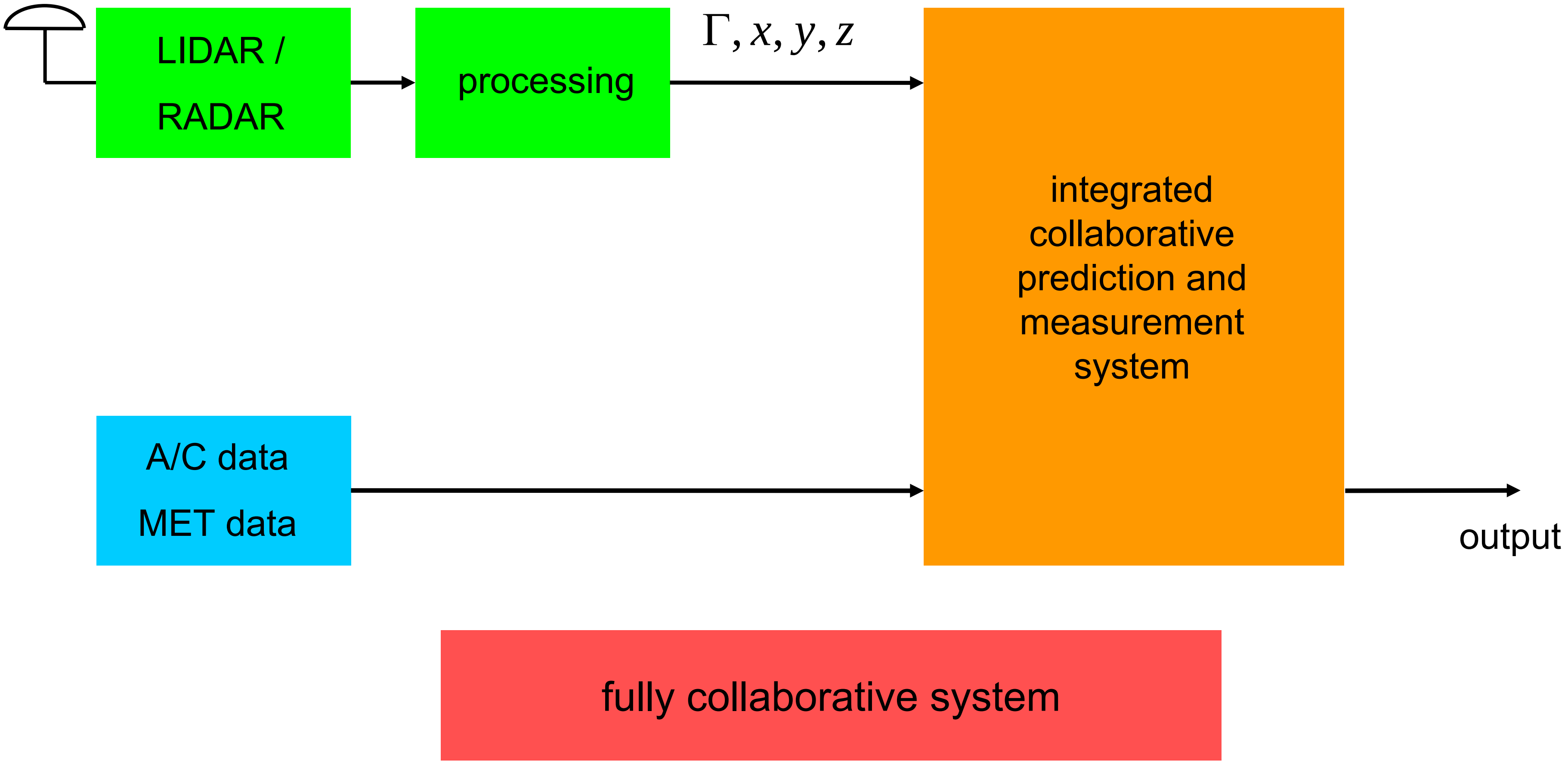
model and sensor independent, but collaborative output

Loose coupled approaches



model accepts and processes corrections from collaboration

Loose coupled approaches



Conclusions

- model predictions and measurement are complementary
- taking advantages by collaboration of both
- first implementation results show proof-of-concept
  - keeping in mind, that the WV behaviour is not modelled within the filters yet

    ➔ results show that fusion approach is applicable for future WV prediction and detection systems
  - integration of prediction model should be proposed
- further applications
  - enhance detection ability of sensors

  ➔ involve processing of sensor into collaborative system

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Thank you for your attention!

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