SALOMÉ'S USER DAY

Optimal calibration of Telemac-2D models based on a data assimilation algorithm

Cédric Goeury, Angélique Ponçot, Jean-Philippe Argaud, Fabrice Zaouï, Riadh Ata, Yoann Audouin

27 March 2018
Content

1. CONTEXT
2. CALIBRATION AND DATA ASSIMILATION
3. COMPUTATIONAL ENVIRONMENT
4. ALGORITHM VERIFICATIONS
5. RESULTS
1. Context: Maritime application (1/2)

- Tidal turbine sector is rapidly growing, towards a commercial industrial phase

- Several critical aspects to consider in the evaluation of a technology:
  - Performance
  - Technology maturity
  - Costs
  - Installation et maintenance
  - Environmental impact

- Future issues:
  - Farm Effects (wake effect, machine interactions)
  - Development of a tidal energy industrial sector
  - Protocols («best practices»)
  - Consenting process
1. Context: Maritime application (2/2)

Tidal farm resource assessment

- Spatial variations => Where?
- Time variations => From instantaneous power (MW) to energy yield (MWh/y)
- Function of power of the current velocity => uncertainty on velocity induces an important error on the power estimation (currently about 30%)

How?
- Numerical modelling
- Measurement campaigns

\[
P = \frac{1}{2} \rho c_p S_{\text{rotor}} U^3
\]

\[
E_{\Delta T} = P \cdot \Delta T \quad E_{\text{year}} = \sum_{\text{year}} P \cdot \Delta T
\]
1. Hydro-environmental modelling
Complex process and uncertain data

Approximated model:
• TELEMAC-MASCARET system
• Not well-known parameters
• Uncertain datas: initial condition, boundary conditions, weather forcing etc

Observations: incomplete view of the process but not approximated

Uncertainty Quantification:
Impact of uncertainty on the output of the model – sensitivity analysis etc

Data Assimilation:
Compromise between the approximated model and measurements to better simulate and forecast
2. What is Data assimilation?

- **The model outputs are imperfect** because many sources of uncertainty, which must be corrected to better represent the physical system of interest, by combining « observations or measurements » and the « numerical simulation by the model », using optimal calibration by data assimilation methodology.

**Aim of data assimilation:**
Find the best compromise between model and measurements to better simulate and forecast the state of the system.

- **Choice of control vector:** $x$ can be parameters of hydraulic model, initial conditions, etc.

![Diagram](https://via.placeholder.com/150)
2. Optimal calibration: general principle

The classical cost function of data assimilation express the misfit between measurements and numerical model simulation:

\[ \text{Min} \left\{ \frac{1}{2} \| X^b - X \|_B^{-1}^2 + \frac{1}{2} \| Y^o - H(X) \|_R^{-1}^2 \right\} + \ldots \]

In a more mathematical view: the numerical model is embedded in an operator \( H \) to compare measurements \( Y \) with simulation \( H(X) \) for the given parameters \( X \). Optimal parameters are searched by minimizing this cost function under feasibility conditions, with prior knowledge on the parameters:

\[
J(X) = \frac{1}{2} \| X^b - X \|_B^{-1}^2 + \frac{1}{2} \| Y^o - H(X) \|_R^{-1}^2
\]

Minimization problem solved used a classical iterative variationnal method:

- It requires calculation of the gradient of the cost function with respect to the parameters
- It relies on the estimation of the derivatives of TELEMAC calculation with respect to the parameters
Minimization problem solved used a classical iterative variationnal method:

- It requires calculation of the gradient of the cost function with respect to the parameters
- It relies on the estimation of the derivatives of TELEMAC calculation with respect to the parameters

Various methods to get these derivatives informations (each with pro/con), requiring in practice validation and previous sensitivity analysis.
3. COMPUTING ENVIRONMENT

Example of possible Cross-functionalities based on HydroSolver:

- Coupling facility:
  - Multidomains (1D-2D for example)
  - Multiphysics (water quality, sedimentology, etc.)

- Uncertainty Quantification
- Data Assimilation
- Shape optimization
- And so on…
3. How does it work?

Based on the interoperability of hydraulic models and ADAO in SALOME-HYDRO

Interoperability:
Capacity of the software to run and share informations with other different softwares

Have building blocks for each software that can be easily assembled to model complex systems
4. Algorithm verifications: Calibration of friction coefficient (1/2)

- **Numerical configuration:**
  - Telemac-2d model with a finite element mesh of 551 triangles
  - Initial guess of roughness coefficient imposed to 15
  - Boundary conditions:
    - upstream, a discharge is set to $50 \, m^3/s$
    - downstream, a water depth is imposed to $1 \, m$

- **Optimization configuration:**
  - “identical-twin-experiment” framework:
    - Observations are water depth on all domain computational nodes at times $T = [0, 2000, 4000, 6000, 8000, 10000]$
    - Observations are synthetic water depth generated numerically with a Strickler coefficient of $35 \, m^{1/3}s^{-1}$

- **Objective:**
  - Exploit the measurements and observations in optimal manner in Telemac, in order to identify the most probable roughness coefficient
4. Algorithm verifications: Calibration of friction coefficient (2/2)

To conclude:
- Well behavior of the data assimilation computation chain allowing to find automatically an optimal roughness coefficient.
5. Numerical configuration

- **Numerical configuration**
  - Telemac-2d model (35361 elements)
  - Boundary condition:
    - Tidal TPXO database imposed

- **Optimization configuration:**
  - Existing 6-month and two-point measurement campaign (2009/2010):
    - Averaged velocity
    - Water depth

- **Objective:**
  - Exploit the measurements and observations in optimal manner in Telemac, in order to identify the most probable tidal parameters
5. Sensitivity analysis results

- **Choice of calibration parameters:**
  - Friction coefficients ($K_1, K_2$ because two friction areas), tidal parameters (sea level, multiplicative coefficients of the water depth and the velocity amplitude)

- **Coefficient to calibrate sea level $\rightarrow$ A**
- **Coefficient to calibrate tidal range $\rightarrow$ B**
- **Coefficient to calibrate velocity range $\rightarrow$ C**

- Sensitivity analysis based on chaos polynomial decomposition:
  
  Results show the negligible effect of friction coefficients ($X_1(10^{-4}\%), X_2 (10^{-4}\%)$) compared to the tidal calibration parameters ($X_3(99\%), X_4(10^{-1}\%), X_5 (10^{-2}\%)$)
5. Results after tidal parameter calibration

Comparison of the evolution of the calculated water depth with and without calibration

Comparison of the evolution of the calculated velocity with and without calibration

Optimal calibration of Telemac-2D models based on a data assimilation algorithm | 27/03/2018
6. CONCLUSIONS AND OUTLOOKS

- Implementation of a computation chain under the SALOME platform for data assimilation in hydraulics based on the interoperability of TELEMAC-2D and ADAO software
  - Implementation feasibility of data assimilation algorithms allowing for instance the calibration of hydraulic studies
  - The computation chain is running in parallel

**Outlooks**

- Apply the computational chain on the Gironde estuary in order to take into account the bathymetry change induce by dredging to recalibrate the most influential parameters of the model from the available observation datas
- Based on the same process, construct a shape optimization tool as shown in the following example:
Thank you for your attention