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


1 Pherosensor-toolbox: a Python package for 2 Biology-Informed Data Assimilation

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7 Summary

8 Insect pests are a major threat for agricultural systems ([Oerke, 2006](#)), leading to an intensive
9 use of pesticide for crop protection with non-sustainable drawbacks on environment, biodiversity
10 and human health. Most of insects produce pheromones for conspecific communication, making
11 pheromone sensors a good tool for early specific detection of pests, in order to reduce pesticide
12 use in a precision agriculture context ([Gebbers & Adamchuk, 2010](#)).

13 Pheromone-toolbox is a Python package containing numerical tools for pheromone sensor
14 data assimilation to infer the position of emitting pest insects. It contains specific tools to
15 model pheromone propagation and solve the corresponding inverse problem to determinate
16 emitters position taking into account the environmental context (wind, landscape, vegetation...).

17 A specific focus is put on the integration of biological knowledge of pest behavior during
inference.

Statement of need

20 Unlike other generic tools for data assimilation, such as DAPPER ([Raanes et al., 2024](#)), OpenDA
21 ([Ridler et al., 2014](#)) or ([Nerger et al., 2005](#)), Pherosensor-toolbox is a context-specific
22 application-oriented package specifically designed to solve the inverse problem of inferring
23 the source term (i.e. pheromone emitters position and emission rates) within a Chemical-
24 Transport Model (CTM) modelling pheromone propagation in an agricultural landscape.
25 Additional feature is the possibility to inform the data assimilation with insect behavior, such
26 as the population dynamics partial differential equations (PDE), to get Biology-Informed
27 Data-Assimilation (BI-DA). BI-DA aims to counter-balance data scarcity with prior biological
28 knowledge. An other additional feature to come is optimal sensor placement tools to find the
29 most informative sensor placement for assimilating the sensors data and inferring the source
30 term of the CTM.

31 Outlook

32 Direct CTM problem

33 Pherosensor-toolbox first contains numerical tools to solve a 2D CTM, i.e. the equation
34 defined on a landscape Ω and a time span $(0, T)$ as

$$\frac{\partial c}{\partial t} - \nabla \cdot (\mathbf{K} \nabla c) + \nabla \cdot (\vec{u}c) + \tau_{loss}c = s \quad \forall (x, y) \in \Omega, \forall t \in (0; T) \quad (1)$$

35 where $c(t, x, y)$ is the local pheromone concentration, \mathbf{K} is a diffusion coefficient, \vec{u} is a wind
36 field, τ_{loss} represents vertical loss of pheromone (including vertical transport and vegetation-
37 specific deposition), and s is the quantity of pheromone emitted. Note that \mathbf{K} , \vec{u} and τ_{loss}
38 are known parameters, whereas $s(t, x, y)$ is the source term to estimate. The latter is related
39 to pest density $p(x, y)$ by the relation $s = q(t)p(x, y)$ where q is a time pheromone emission
40 per insect.

41 Pherosensor-toolbox includes a finite volume solver defined on a cartesian scatter grid with
42 implicite and semi-implicite time-schemes.

43 BI-DA to solve the inverse problem

44 We define BI-DA with the following optimization problem: find the optimal quantity of
45 pheromone emitted in time and space $s_a(t, x, y)$ such that \$

$$s_a(x, y, t) = \underset{s(x, y, t)}{\operatorname{argmin}} j(s) \text{ with } j(s) = j_{obs}(s) + j_{reg}(s) \quad (2)$$

46 \$ where j_{obs} is the observation loss and j_{reg} is a regularization term. Namely

$$j_{obs}(s) = \|m(c(s)) - m^{obs}\|_{\mathbf{R}^{-1}}^2$$

47 where $c(s)$ is the concentration map obtained by solving the CTM [Equation 1](#) with second
48 member s , m^{obs} are noisy observations with covariance \mathbf{R} , and $c \mapsto m$ is an observation
49 operator.

50 In the BI-DA framework, the term j_{reg} involves biological priors including LASSO (pest sparsity
51 in time and space), group-LASSO (pest sparsity in space), Tikhonov (pest favorite habitat),
52 log-barrier (inappropriate habitat) or pest population dynamics. For population dynamics,
53 $j_{reg}(s) = \|\mathcal{M}(s) - \gamma\|_2^2$, i.e. the regularization aims at minimizing the residual of a PDE or
54 ODE model defined with the differential operator \mathcal{M} and a background value γ .

55 Pherosensor-toolbox provides gradient-based (gradient descent or proximal gradient) varia-
56 tional optimization methods to solve [Equation 2](#), where the gradient $\nabla_s j_{obs}(s)$ is obtained
57 by solving the adjoint model of the CTM. It also provides tools to implement the population
58 dynamics PDE or ODE-based regularization.

59 Postprocessing

60 Pherosensor-toolbox comes with several plotting functions to display differences and bench-
61 marks between a ground truth and the estimate s_a including spatial maps or pest presence
62 maps defined with level sets.

63 Related works

64 Pherosensor-toolbox has been used in a publication introducing the BI-DA framework and
65 assessing the impact of incorporating prior biological knowledge on the estimation accuracy
66 ([Malou et al., 2024](#)). This publication also incorporates mathematical developments to include
67 any type of PDE-based population dynamics regularization. The optimal placement tools, that
68 will be soon added to Pherosensor-toolbox, will be used to study the optimal placement in
69 the landscape of pheromone sensors in order to enhance the accuracy of pest localization, and
70 to study methodologies of sensors placement and replacement.

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