NTNU | Norwegian University of Science and Technology

SPECIALIZATION / MASTERS PROJECT

Adil RASHEED / 22.April.2021

www.hybridmodelling.com

- Preferred way of working

1. Start writing in an overleaf document from start.
2. No fixed time slots for meeting. Contact me as and when needed both within or outside the working hour if you find me online on teams.
3. Aim at writing a journal article

– Project topics

Physics guided machine learning

Equation / knowledge discovery

Hybrid Analysis and Modeling - COSTA

3D CAD models in ML

Pose estimation using 3D CAD models

Railway track condition monitoring

Floating wind turbine stabilization

Unity ML

Physics Informed Neural Network

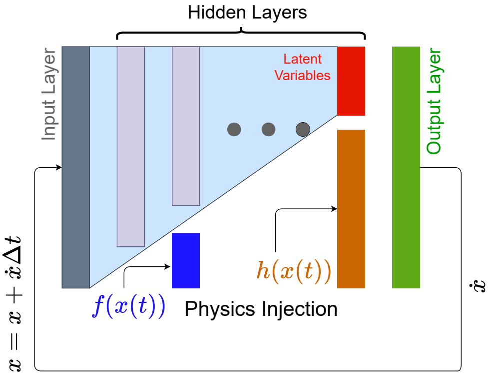
Doppler velocity logger

Biological acoustic and i mage signal analysis

Physics guided machine learning - Project description

The project aims to answer several research questions pertaining to the injection of domain knowledge in neural networks to

1. reduce the amount of required training data
2. improve the accuracy of the model reduce the uncertainty in prediction
3. speed up the training phase
4. simplify the model architecture

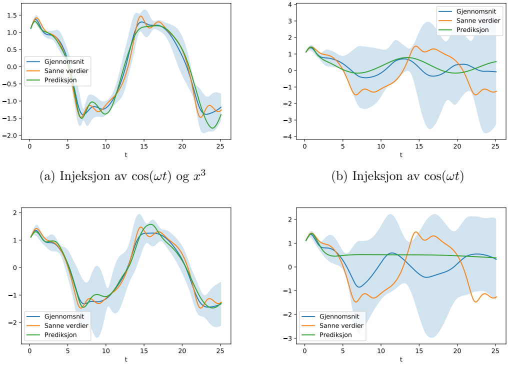


$$\dot{x} = f(x)g(x) + h(x) + \epsilon$$

Physics guided machine learning - Relevant work

Contact for more details about the idea and the tasks.

Pawar, S., San, O., Aksoylu, B., Rasheed, A. and Kvamsdal, T. Physics guided machine learning using simplified theories. Physics of Fluids, 33, 011701, 2021. Download article



(a) Injeksjon av $\cos(\omega t)$ og x^3 (b) Injeksjon av $\cos(\omega t)$

(c) Injeksjon av x^3 (d) Uten injeksjon

Figur 7: Gjennomsnittet over 10 initialiseringer med 95% konfidensintervall. Prediksjonskurven viser resultatet fra en av disse initialiseringene.

Duffing-ligningen equation

$$x'' = \gamma \cdot \cos(\omega t) - \delta \cdot x' - \alpha \cdot x - \beta \cdot x^3 - \epsilon \cdot x^5$$

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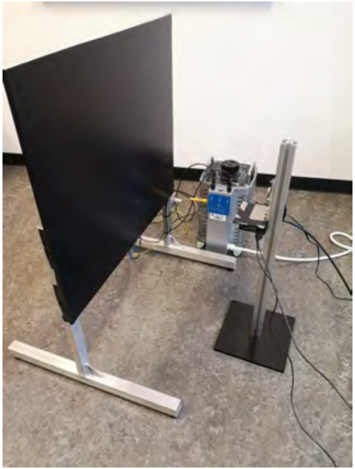
Equation / knowledge discovery - Project description

Generally, equations are derived from the first principles using the well-known laws of physics. However, in the absence of good enough knowledge of physics, it is difficult to derive the equations. Fortunately, it is possible to derive highly complex equations and new physics directly from the data. In this project, the students will undertake the following tasks:

1. Design an experimental set-up for generating data
2. Develop methods for preprocessing the data
3. Develop methods based on several regularization techniques and symbolic regression to derive equations directly from the data.
4. Learn to reduce the model and numerical complexity of the physics based models
5. develop new approach to make the approach robust to noise

Equation / knowledge discovery - Relevant work



Discovered equation

$$\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} + \sigma$$

Vaddireddy, H., Rasheed, A., Staples, A. E. and San, O. Feature engineering and symbolic regression methods for detecting hidden physics from sparse sensor observation data. Physics of Fluids, 32, 015113, 2020. (Editor's Pick)
Download article

Hybrid Analysis and Modeling - COSTA - Project description

Ordinary and partial differential equations are frequently encountered in a wide array of engineering applications. There are several challenges which one needs to resolve like

1. physical quantities and parameters are not known. for eg. thermophysical properties of materials might not be precisely known for heat transfer problems
2. equations are computationally too demanding to solve

In this context the student will undertake the following tasks:

1. Develop numerical methods for solving ODE and PDE
2. Develop data-driven models to solve the equations
3. Develop a hybrid technique to outperform both physics- and data-driven techniques

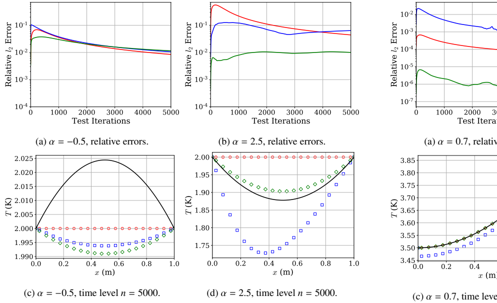
Hybrid Analysis and Modeling - COSTA - Relevant work

$$\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} + \sigma$$

where σ is unknown

Blakseth S., Rasheed A., Kvamsdal T., San O., Hybrid Analysis and Modeling Using the Corrective Source Term Approach, To be submitted

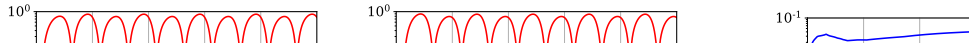
To be done in collaboration with SINTEF Digital. Contact for more information.



(− Exact, ○ PBM, □ DDM, ◇ HAM)

Figure 10: Solution 3, extrapolation: Comparison of relative errors and final temperature profiles for $\alpha = -0.5, 2.5$ (— Exact, ○ PBM, □ DDM, ◇ HAM). HAM is most accurate for $\alpha = 2.5$, while all methods fail to provide qualitatively correct predictions for $\alpha = -0.5$.

Figure 12: Solution 0, emperature profiles fo HAM's predictions are b is least accurate.



3D CAD models in ML - Problem description

Shearing, mirroring, rotation and translation are the common methods used for image augmentation. The current project proposes to exploit the information stored in the 3D CAD models of the object to augment the training dataset in a purely virtual environment.

3D CAD models in ML - Relevant work

Tasks

1. Create 3D models using the provided scripts
2. 3D print the CAD models to generate physical models
3. Develop scripts to photograph the 3D CAD models virtually to generate synthetic data for training. This can also involve augmenting the background and applying transformations to the CAD models directly to augment the training data.
4. Take the photographs of the 3D printed objects and create a test set
5. Develop two different class of object classification algorithms one based on compressed sensing and another based on convolutional neural network
6. Train, validate and test the algorithms.

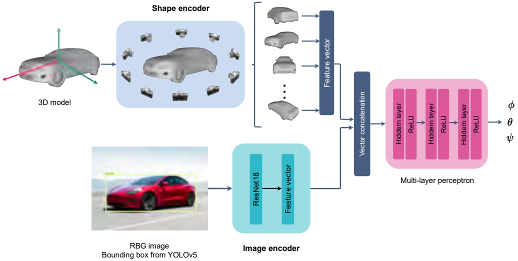
Contact for more information

This work will be done in collaboration with SINTEF Digital

Pose estimation using 3D CAD models - Project description

3D pose estimation is important. Currently it employs expensive instrumentation and sensor to achieve this. We propose to develop algorithms which will be able to do pose estimation using 2D images taken under different lighting conditions.

Pose estimation using 3D CAD models - Relevant work



1. Refine the experimental setup for data acquisition
2. Develop algorithms to estimate pose directly from 2D images
3. Extend the previous work by adding option to estimated translations in addition to rotation
4. Test the sensitivity of the algorithm to shape and size

Sundby, T.; Graham, J.M.; Rasheed, A.; Tabib, M.; San, O. Geometric Change Detection in Digital Twins. Digital 2021, 1, 111-129. Download article

Railway track condition monitoring - Problem description

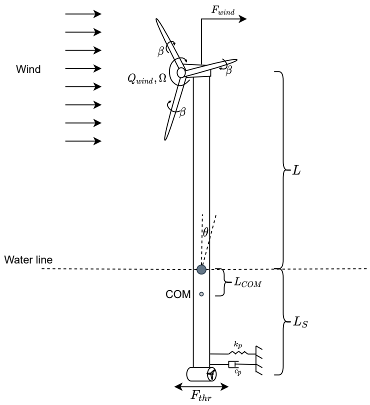
Roger 1000 is a movable railway track condition monitoring train. The train uses different technologies such as accelerometers, laser scanner, ultrasound, imagine sensors, etc. to describe railway track condition when the train driving through it. Although many data are measured by the train, to be able to tell the status of the track often still requires manual effort. For instant, it takes one or few employees to analyze the data, compared it to the standard, draw a conclusion of the status of the track, and eventually notify railway track owner (Bane NOR) if attention needs to be paid. One downside of such manual work/task is that, sometime important events might be missed due to human factor. Over the years, Bane NOR has collected good amount of data and it seems like it might be enough to use supervised machine learning to perform the above mentioned task.

Railway track condition monitoring - Expected tasks

1. train/develop ML to be able to identify most (if not all) anomalies (event log) in the historical data.
2. Develop ML algorithm that can automatically identify anomalies in the data with high certainties.
3. Use of ML learning to automatically notify any unwanted event via the data and if possible, integrate the algorithm into existing data management system on the train.

This work will be co-supervised by Assoc. Prof. Albert Lau from the Department of Civil and Environmental Engineering.

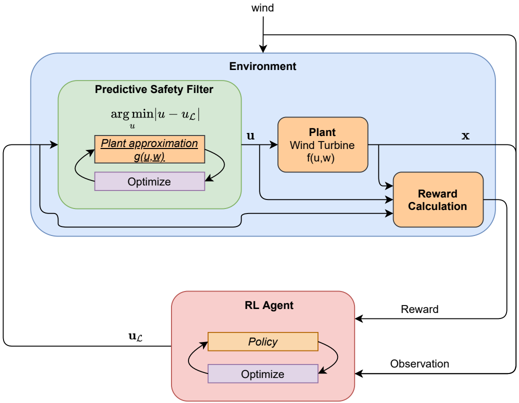
Floating wind turbine stabilization - Problem description



Stabilization of floating offshore wind turbines. It has been shown that Reinforcement Learning can be used for achieving such tasks however, a lack of guarantee on the safety and their blackbox way of operating makes their application limited. The current work will address these issues.

Floating wind turbine stabilization - Relevant work

1. Reinforcement learning
2. Model predictive control
3. Combining the RL and MPC to provide safety guarantees



Masters thesis of Halvor Teigen and Vebjørn Malmo

Unity ML - Project description

Creating a simulator for a physical process, including visual rendering of the system, is a non-trivial task in Python. Using Python libraries to render requires tedious low-level coding, and the rendering can quickly become the computational bottle-neck in the simulation. This makes prototyping and debugging new simulation environments a time-consuming task that is prone to human error. Utilizing a more high-level interface for prototyping new environments using a well-established real-time physics engine can significantly improve the speed of developing new simulations, with the added benefit that the resulting simulations can easily be made visually pleasing.

Unity ML - Background

The Unity Development team is currently developing *The Unity Machine Learning Agents SDK* (ML-Agents), currently in beta, as an open-source Unity plugin that enables games and simulations to serve as environments for training intelligent agents [1].

Agents can be trained using reinforcement learning, imitation learning, neuroevolution, or other machine learning methods through a simple-to-use Python API. Further, the Python API features an interface to the de-facto standard OpenAI Gym machine learning framework [2].

[1] https://unity3d.com/how-to/unity-machine-learning-agents

[2] https://gym.openai.com/

Unity ML - Tasks

A potential pre-project could consist of developing a simulation in the Unity game engine using the ML-Agent plugin, which will be interfaced to the OpenAI Gym framework, and potentially also Stable-Baselines[3] or OpenAI Baselines[4] implementations of state-of-the-art RL algorithms.

[3] https://stable-baselines.readthedocs.io/en/master/
[4] https://github.com/openai/baselines

Physics Informed Neural Network - Project description

Title: Physics-informed deep learning for identification of flow and deformation parameters in poroelasticity:
PINN models have created a new trend at the intersection of machine learning and computational modelling research. The main idea behind such models is the encoding of the governing physical laws (in the form of partial differential equations and other supplementary equations) such that the deep learning model learns both from data and the physical laws.

Physics Informed Neural Network - Project description

Poroelasticty refers to the coupled flow and elastic deformation processes in porous media and has important applications in various disciplines of science and engineering such as material science, geomechanics and reservoir engineering. The governing equations of poroelasticity are a combination of the overall mass balance equation, the equilibrium or linear momentum balance equation and the linear elastic constitutive equations for stress-strain relationships. The flow and deformations parameters of the porous medium are important components in the governing equations of poroelasticity. These parameters are usually difficult to determine from experiments. Data-driven deep learning models may be used to estimate these parameters more accurately. Inverse problems in static poroelasticty will be studied to illustrate the potential offered by physics-informed deep learning. For the purpose of the study here, the data for flow and deformation will be represented by poroelastic problems with known analytical solutions.

Physics Informed Neural Network - Tasks

1. Do a literature survey
2. Understand the numerical solvers and generate data
3. Develop PINN architecture and learn to optimize it with custom cost function

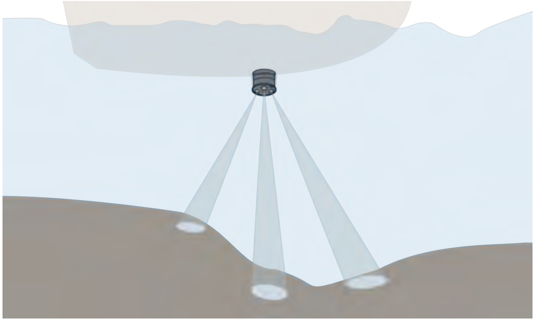
Bekele, Y.W., Physics-informed deep learning for one-dimensional consolidation Download Article Physics-informed deep learning for one-dimensional consolidation

Doppler velocity logger - Problem description

Utilizing a Doppler Velocity Logger to measure an object's velocity enables correction of any time-varying bias introduced in positional estimate integration processes. This correction requires a reliable and robust bottom-tracking algorithm to detect the sample-window stemming from the bottom, thus obtaining the samples to be evaluated for Doppler shift. Considering all variations in the received amplitude-signals requires an increasingly more complex heuristic algorithm that would require knowledge of each variation. Therefore, a Machine Learning approach to predict the sample-windows in the DVLs amplitude-signals, obtaining a high-accuracy, generalized tool for bottom-detection seems like a promising approach.

Doppler velocity logger - Relevant work

Contact for more information.
This work will be done in collaboration with NORTEK.



Marie Skatvedt

Biological acoustic and i mage signal analysis - Problem description

The project aims to extend the work on developing a generalized workflow for analyzing biological acoustic and image signals for anomaly detection.

Elsetrønning, Andrine; Rasheed, Adil; Bekker, Jon; San, Omer. (2021) On the effectiveness of signal decomposition, feature extraction and selection to identify lung crackles. Download

Thank you for your attention

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