Gaussian process model incorporating energy conservation law

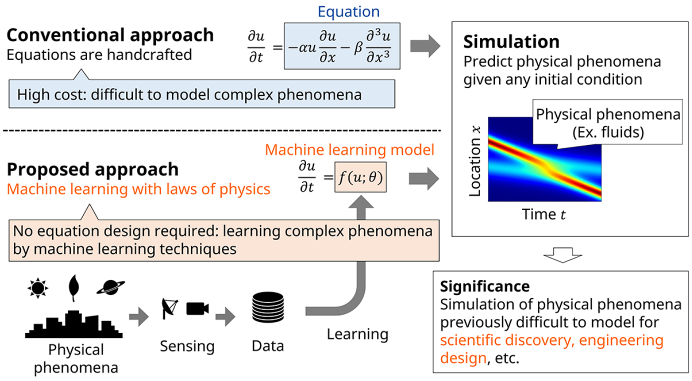
Machine learning that reproduces physical phenomena

Abstract

Our research question aims to reproduce the underlying behavior that adheres to the laws of physics using machine learning techniques. We propose a novel Gaussian process model that incorporates the theory of Hamiltonian mechanics. One advantage of our technology is that it can simulate physical phenomena without handcrafted equations. Our experiments show that our technology accurately simulates physical phenomena that follow energy conservation laws even in noisy and small data scenarios. This research enables us to automatically construct simulators for complex physical phenomena from observed data. We expect our research to contribute to the development of such science/industries as weather forecasting as well as improving the efficiency and the quality of aircraft design.

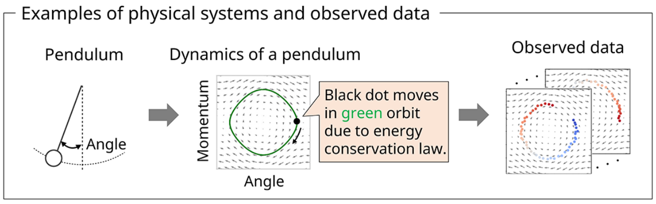
Data-driven physics simulator

We use machine learning to reproduce underlying behavior that follows laws of physics from data. Our technology allows for simulating physical phenomena without handcrafting equations.

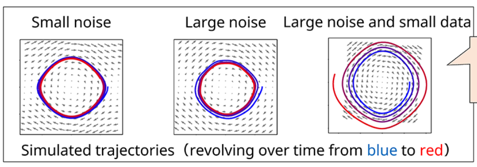


Limitations of existing methods

Our experiments show difficulty of existing methods to accurately reproduce physical phenomena. Significant performance degradation was observed especially in noisy and small data scenarios.

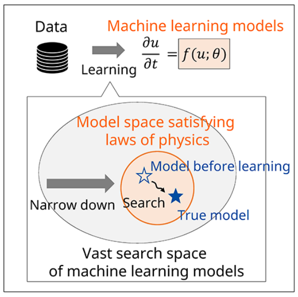


Results of applying a standard neural net to observed data for pendulum



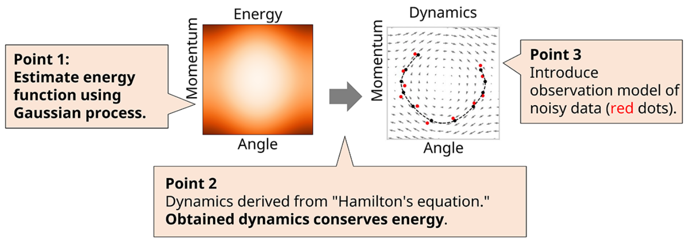
Introducing laws of physics

Difficulty
Machine learning models are quite expressive and have potential to adequately model large, complex physical phenomena. However, due to their high expressive power, it is complicated to infer models that accurately reproduce physical phenomena from a vast search space.

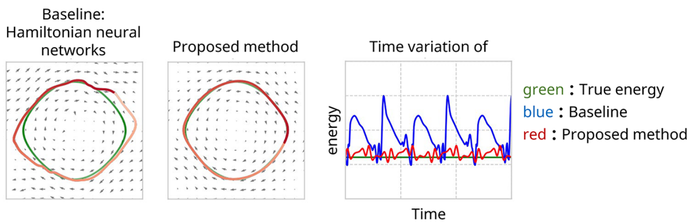


Key idea
By introducing prior knowledge of physics, search space can be narrowed down to effectively estimate a model that accurately reproduces physical phenomena.

Proposed method [1]
We present a novel technology that incorporates "Hamiltonian mechanics" into "Gaussian process."



Experimental results
Our proposed method accurately simulated physical phenomena that follow energy conservation law even in noisy and small data scenarios.



References

[1] Y. Tanaka, T. Iwata, N. Ueda, "Symplectic spectrum Gaussian processes: Learning Hamiltonians from noisy and sparse data," in *Proc. Advances in Neural Information Processing Systems (NeurIPS)*, 2022.

Contact

Yusuke Tanaka
Learning and Intelligent Systems Research Group, Innovative Communication Laboratory