Introducing AI to atomic clocks for improving holdover

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We are investigating new ways of improving the frequency accuracy and stability of holdover atomic clocks, such as rubidium standards, to operate autonomously for months or years without human intervention. An atomic clock's medium and long-term stability is typically affected by component ageing and environmental effects, which cause systematic frequency shifts, e.g., light shift caused by intensity changes in the optical source that is used to interrogate atoms [1-3]. Compensation algorithms may be used to detect these intensity changes and apply corrections, e.g., to the frequency stabilised oscillator, to mitigate these undesirable frequency shifts [1]. The effectiveness of the corrections depends on the algorithms sensitivity and ability to interpret the many simultaneously occurring and often uncorrelated environmental shifts, which can be described as interleaved linear and non-linear processes. Suitably trained neural networks offer a high-level solution as their architecture is honed to solve such complex problems.

The development of suitable artificial neural network (ANN) architectures for holdover atomic clocks provides three potential solutions: anomaly detection (supervised learning), automated optimisation- analysis of 'big' data, and automated discovery (unsupervised learning). The ANN capability to detect, analyse, predict, and take corrective actions on atomic clock behaviour such as ageing and environmental changes is novel. Corrective actions may involve correcting the oscillator frequency or adapting/switching components. On correcting for known factors, the residual holdover error remaining is composed of sensitivities to factors that are treated statistically [4].

We are developing a neural network architecture in Python object-oriented programming with each neuron constructed as a complex data object within the class 'neural network' with a feedback loop (back propagation) intended initially for supervised learning. We discuss its introduction to our holdover atomic clocks and its potential applications.

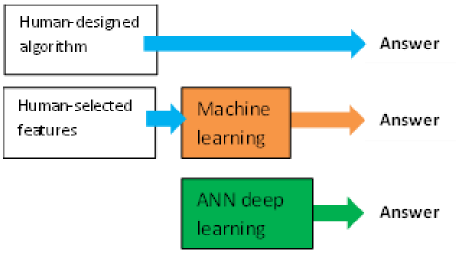

Figure 1 Block diagram indicating the development of deep learning.

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[1]V. Formichella, J. Camparo, and P. Tavella, "Mitigation of Lamplight-Induced Frequency Jumps in Space Rubidium Clocks", IEEE transactions on ultrasonics, ferroelectrics, and frequency control, vol. 65, no. 6, June 2018

[2]J. Camparo, "Does the light shift drive frequency aging in the rubidium atomic clock?", IEEE transactions on ultrasonics, ferroelectrics, and frequency control, vol. 52.7, p. 1075-1078, 2005

[3]V. Formichella, J. Camparo, and P. Tavella, "On-orbit GPS RAFS lamplight variations: Statistics of lamplight jumps," in Proc. PTTI, 2017, pp. 291–298.

[4]Specifying Holdover Performance Bill Dickerson, Arbiter Systems, Inc, 2020 (Accessible online: https://www.arbiter.com/files/product-attachments/PD0057900_Specifying_Holdover_Performance.pdf)