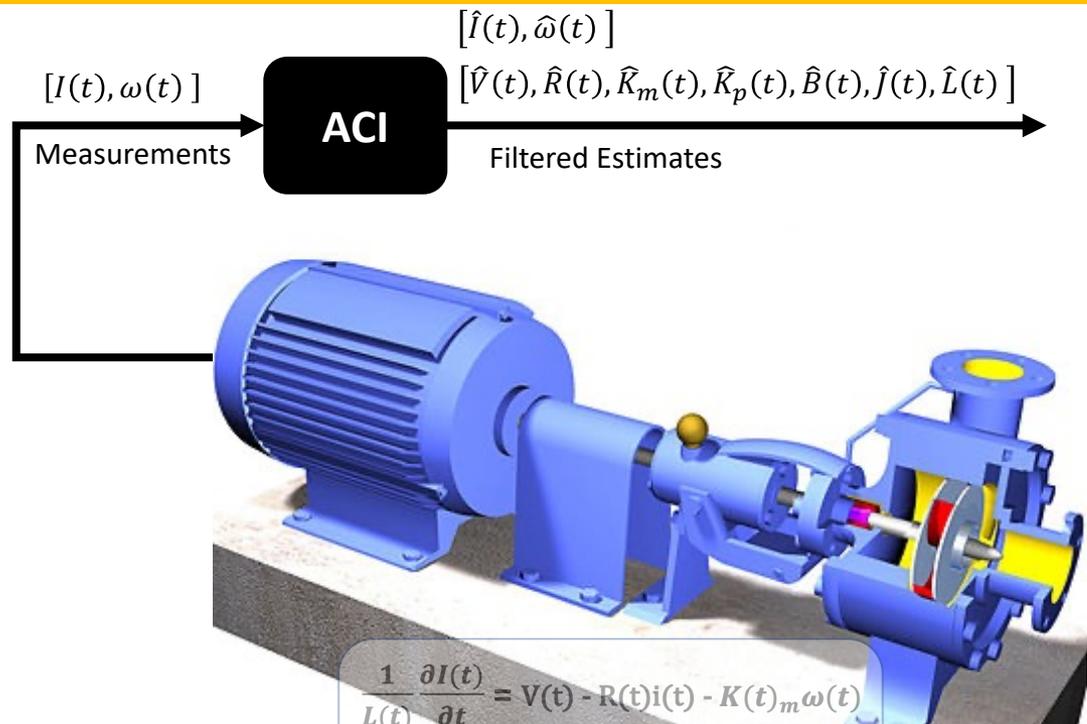# Simulated Demonstration of Artificial Cerebellar Intelligence (ACI)

- A motor-pump is simulated via a simple system of ordinary differential equations, with seven independent physical parameters time-varying.

- In this example some of the physical parameters of the motor pump are behaving in nonsensical ways. However, the ACI does not receive input concerning the parameters.

- The ACI utilizes two independent outputs, the current and shaft speed, to accurately estimate the seven time-varying parameters.

$$[I(t), \omega(t)]$$

Measurements

ACI

$$[\hat{I}(t), \hat{\omega}(t)]$$
$$[\hat{V}(t), \hat{R}(t), \hat{K}_m(t), \hat{K}_p(t), \hat{B}(t), \hat{J}(t), \hat{L}(t)]$$
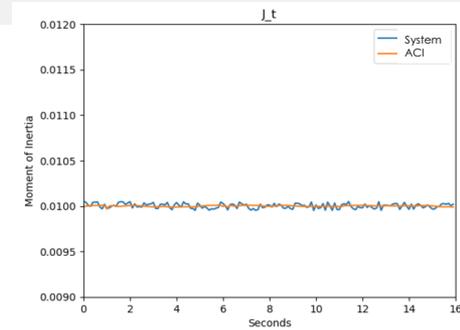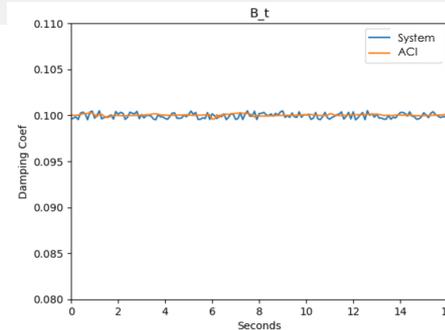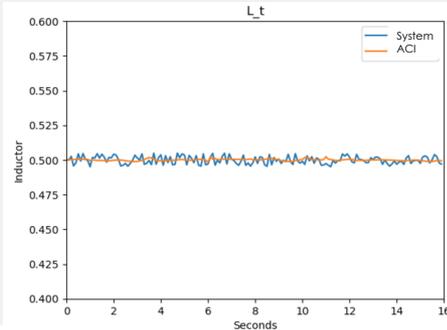
Filtered Estimates

$$\frac{1}{L(t)} \frac{\partial I(t)}{\partial t} = V(t) - R(t)i(t) - K(t)_m \omega(t)$$

$$\frac{1}{J(t)} \frac{\partial \omega(t)}{\partial t} = K(t)_p i(t) - B(t)\omega(t)$$

Simulation

Page 1/4 and Appendix

Simulated* Demo of ACI

- The lower image is the **prediction errors** on the two signals that ACI is monitoring, current and speed.

- The three upper images represent independent parameters (Inductor, Damping Coefficient, Moment of Inertia) that are simulated as behaving stochastically with a constant mean.

- For these parameters, despite the agitation in the system, the ACI estimates the correct constant means, based only on monitoring the current and speed.
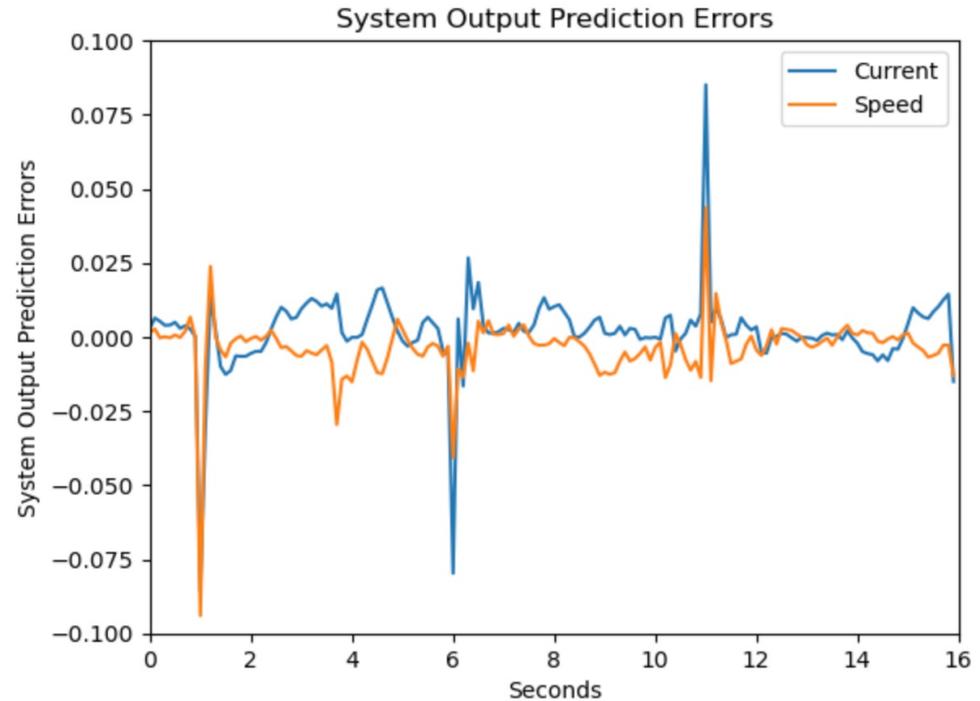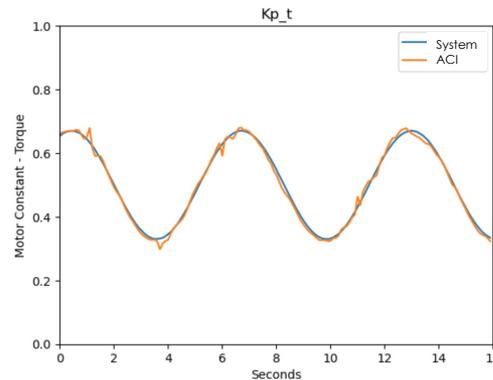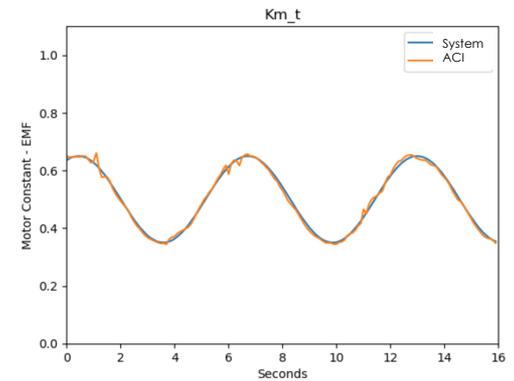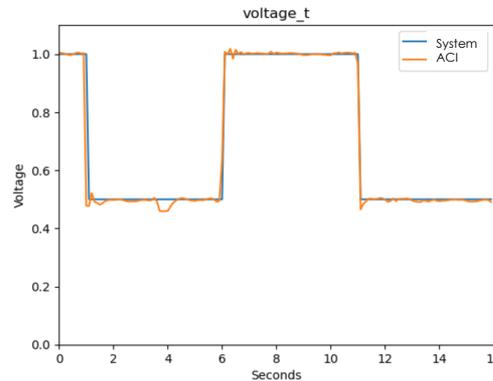

* Units are intentionally omitted from the data descriptions.

Simulated* Demo of ACI

- The images show the values of the remaining four independent time-varying parameters, which are simulated with sinusoids and step functions (i.e., voltage, motor emf, motor torque, electrical resistance) with noise.

- The images demonstrate the ACI performs accurately, estimating the parameter behaviors.

- **Underdetermined System Real-Time Result:** <u>Seven</u> accurately estimated time-varying independent parameters, based on monitoring only <u>two</u> independent system outputs.
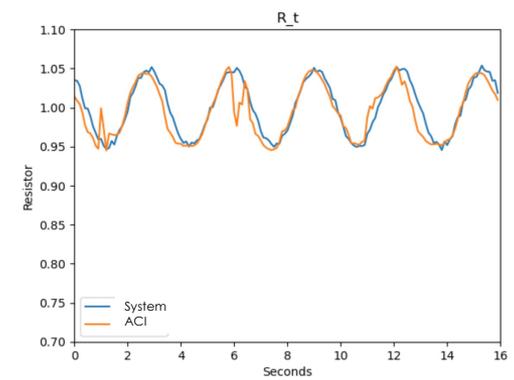

* Units are intentionally omitted from the data descriptions.

Simple Simulated Demonstration of ACI, Notes

- While the demonstrated simulated motor-pump estimation problem can potentially be solved by an EKF method once you know its equations, most real-world systems are far more nonlinear or only partially understood.

- ACI makes no assumptions about linearity or system complexity—it learns directly from simulations and data, which may be of substantially reduced-order and poorly understood.

- It also has no theoretical limits concerning how many (observable) independent parameters can be estimated from a given number of independent outputs.

- ACI implements closed-loop state and parameter estimation, i.e., that is dependent on the accuracy of its prediction errors relative to measured system outputs. The prediction errors can be monitored to assess the accuracy of the estimates.

- Because it is trained on reduced-order physics scenarios rather than micro-scale phenomena (think Ideal gas laws versus molecular-scale collision analysis), ACI inexpensively learns an asset and, on deploy, inherently generalizes to (adapts to the particulars) of the asset fleet, estimating hidden multi-modal behaviors, deviations, and failures in first-principles terms.

- No new sensors required: ACI infers hidden parameters from your existing data-streams straight out of the box.

Stratos Perception, LLC Non-Proprietary Information
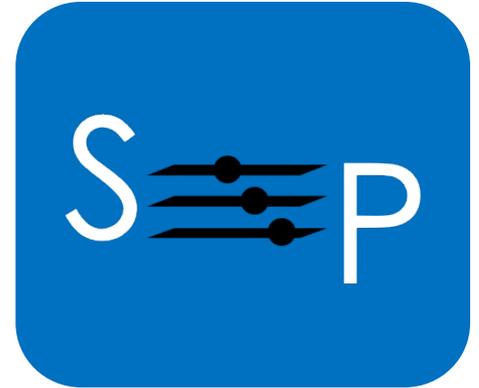
Application to Robotics

- **Motion Control:** In this demonstration, the voltage, which is an input to the motor, is as an unknown disturbance, and is estimated. This type of estimation capability may be invaluable in robotic control systems requiring many coordinated motor-controlled movements.

- **Sensory Feedback:** ACI allows robotics engineers the ability to estimate an unlimited number of unknowns (in theory) based on a small number of sensed outputs. This feature can enable routine estimations of dynamical detailed configurations, center of mass, various moments, and reaction forces based on the sensors that are already available on most current production robots.

- **Performance Guarantees:** ACI utilizes a closed loop nonlinear filtering methodology to achieve its estimates of unknowns based on its prediction errors relative to knowns (i.e., measured outputs). The relative prediction errors may be utilized in real-time analytics to assess confidence in the estimates and to support performance optimization and guarantees.

- **Trust and Safety:** The ACI can be trained to comprehend time-variance in a system-of-systems, with may include the robot and independent artifacts in its environment, including humans. ACI can provide robot control systems accurate sub-millisecond estimates of the behaviors of dynamical stochastic environment artifacts, enabling opportunities for safe robot operations at high speeds in fragile environments.

Appendix