Project Title: DE-FOA-0002224 and LAB 20-2224

**Machine Learning for Real-time Fusion Plasma Behavior Prediction and Manipulation**

*From Institutional PIs: E. Kolemen (PU., Lead-PI), M. Boyer (PPPL), D. Smith (UW-M), J. Schneider (CMU), R. Coffee (SLAC)*

*To: DOE FES Program Manager: John Mandrekas*

Consistent with the task and milestone requirements below is the **Fourth Quarterly Progress Report for 2020**

* *PU:*
  + We curated DIII-D profile data (cleaned, labeled) from databased (task 2.i). Developed initial profile predictors (task 2.ii). This will be tested on DIII-D next quarter.
  + Initial design of the real-time connection box designed and **ordered** for rt-ECE. The system will be tested and hopefully used in the summer for background tests with PCS (task 1.i)
  + ML based ECE analysis for AE started. We made a full databased of all AE activity and ECE data. We are collaborating with UC-Irwin, Bill Heidbrink, for AE classification (task 1.ii)
* *PPPL:*
  + Scripts for generating a database of interpretive TRANSP runs for DIII-D were created to expand the database needed for training physics-based predictive ML models. This database will be completed next quarter and will first be used to expand the range of scenarios over which the DIII-D NubeamNet model is applicable (accepted for publication in Fusion Engineering and Design)
  + Met several times with SLAC, UW, and DIII-D computer staff to design and plan implementation of appropriate hardware solutions for adding FPGAs and digitizers to PCS for ECE and BES.
* *UW-M:*
  + M. Galen Burke has joined the UW ML team. Galen will use his familiarity with the DIII-D BES data ecosystem and his knowledge of ELM physics to assemble a training dataset for BES edge-ML model development.
  + Work to assemble a labelled training dataset for BES edge-ML models has begun. The edge-ML models are the subject of Milestone #1 and a prerequisite for Milestones #2 and #3. A public repository for BES edge-ML code is available on Github: <https://github.com/Fusion-Energy-ML/bes-edge-ml>
  + UW is working with PU, PPPL, and SLAC to spec and implement the hardware interface between BES detector outputs and inputs at an edge-ML compute node.
* *SLAC:*
  + Secured NVidia P4 inference GPU and Xilinx KCU1500 FPGA for inference acceleration
  + Early stage of designing a convolution filter version of Hough Transform in ECE and BES 2D spectrograms
  + Channel covariance in BES shows position-dependence and motivates spatial information being added to the meta-data storage
  + Placed order for 64-channel digitizer to be used to debug and benchmark stream-processing and inference, expected February 2021 arrival.
* *CMU:*
  + Model-based Reinforming Learning (RL): We have developed and tested model-based RL methods for operating on profile dynamics models.
  + Offline RL. We have developed methods that approximate training data density using flow models and then use that density as a reward penalty in offline RL.

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* *PU:*
  + ML based ECE analysis for classification of AE modes led to 91% recognition rate using only raw 40 1-d ECE signals as inputs. The results were submitted to Nuclear Fusion and received positive feedback from the reviewer (ready to resubmit).
  + As a follow up to the previous item, we are developing deep learning-based AE classifiers to analyze the ECE spectrograms. Moreover, we revisited a fraction of the existing dataset and modified the AE labels. This would potentially improve the training of DNN models.
  + *Summer Intern (Eric Ahn):* Given the noisy nature of the ECE spectra, we studied the classical image processing techniques as well as the advanced autoencoder models to enhance the quality of the spectra. This would help for more accurate AE shape and location analysis in the future. The preliminary results will be presented at APS-DPP 2021.
  + As another follow up, we also started to use interferometry diagnostics (CO2) to detect AE modes.
  + Ran an experiment on DIII-D varying the core electron temperature between a low and high target with realtime machine learning forecasts directing the control. A follow-up experiment will attempt full profile control via a different control algorithm in 2022.
* *PPPL:*
  + Created a workflow for running ASTRA simulations based on interpretive TRANSP runs, which will be used to generate a database of predictive transport simulations. A machine learning model trained on both data (Abbate, Conlin *et al* 2021 *Nucl. Fusion* **61** 046027) and simulations will be created for more accurate profile forecasting in FY2022.
* *UW-M:*
* *SLAC:*
  + Installed Concurrent-RT digitizer in host compute node along with 1.5TB nvme storage for training and model temp storage, Nvidia Tesla P40 and P4 inference GPUs, 20 core Intel Xeon Gold CPU, 750GB RAM, Mellanox ConnectX-5 infiniband, and 100Gb dual NIC for connection to existing GraphCore M2000 for both training and inference.
  + New Staff hired Finn O’Shea who will 50% effort on the project with FY21 to FY22 carry forward from the delayed hire being used to secure FPGA and IT effort from TID-AIR engineering. O’Shea has expertise in accelerator systems and anomaly detection with concurrent effort in fault prediction.
  + Coffee has developed a featurization strategy that utilizes low latency operations. He has also built a network of private sector partnerships that are now motivated to make an impact in the Fusion Energy domain.
  + Preliminary SLAC FPGA development has begun with JJ Russel SLAC Neural-network Layers (SNL) is available as a SLAC Git Repository: https://github.com/slaclab/snl
  + The SLAC team has seperately secured additional hardware to upgrade the training resources in order to enable GPT-2 style pretraining of vary large models based on the on-going PPPL and UWisc detector and plasma simulations.
* *CMU:*