Data Preparation to Facilitate Machine Learning Using Pegasus-III Data

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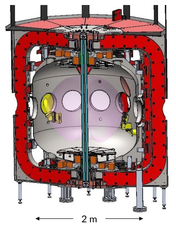
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Pegasus-III Experiment

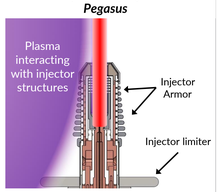
ML Could Enhance Pegasus-III Operations

- Pegasus-III is an ST studying non-solenoidal tokamak plasma initiation
  - solenoid removed to increase BT up to 0.6 T
  - LHI, CHI and EC startup/ramp-up in one device
- LFS-LHI presents many operational challenges
  - short pulse (5-50 ms)
  - radial force balance coupled to PF induction
  - cathode spots & PMI
- Many unique opportunities for ML to improve operational reliability & increase performance
- Part of Open and FAIR Fusion for Machine Learning Applications grant
  - A Multi-Institutional Collaboration To Develop A Fusion Data Platform For Machine Learning Applications With MFE Data [1]
  - Collaboration with UW Data Sciences & other institutions
  - broaden fusion workforce
  - open pathways to collaboration
- Pegasus-III is committed to creating an OPEN/FAIR data set
  - current data is stored on local drive in variety of proprietary formats
  - raw data stored disparately
  - transferring to cloud-based infrastructure
  - creating shot-based data structure with embedded diagnostic meta data

Pegasus-III



LHI injector deployed on Pegasus

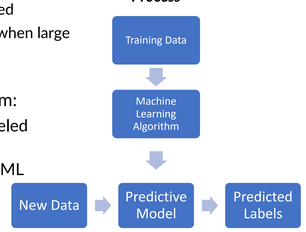




Overview of ML Principles

- Planned work on Pegasus-III will start with labeled data
  - supervised learning for beginning analysis
  - time intensive manual labeling required
  - may try semi-supervised techniques when large data sets available
- Training a supervised ML algorithm:
  - Selecting features & collecting labeled training examples
  - Choosing a performance metric & ML algorithm, then training
  - Evaluating performance of model
  - Change algorithm/settings and tune

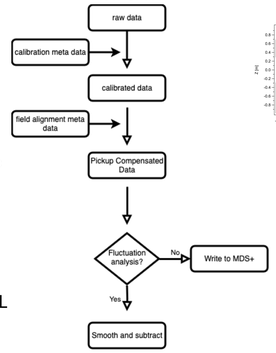
Supervised Learning Process



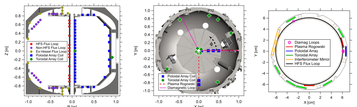
Calibrated Data Loaded to MDS+ with Cloud Storage

- Legacy Pegasus data storage not compatible with ML & easy access
  - raw waveform data stored in individual files
  - Igor Pro file format
  - behind UW Engineering firewall
- MDS+ tree created to store calibrated data with relevant metadata
  - start with magnetics set & coil currents
  - calibrate, remove offsets & misalignment pickup
  - UW cloud storage
- Diagnostic metadata stored on tree
  - model tree updated on hardware change
  - avoid confusion for off-site collaborators
- Next step is normalization of features for ML compatibility
  - features selected based on specific case
  - normalization dependent on feature type

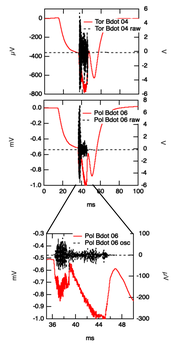
Magnetics Data Processing Flow Chart



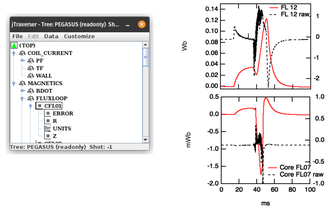
Pegasus-III Magnetics Layout



B-dot Coils



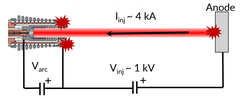
Flux Loops



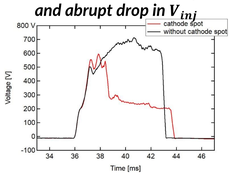
Cathode Spot Detection

- Cathode spots occur when injected current extracted from material electrodes rather than arc plasma
  - drop in injected power (low v_{inj})
  - electrode melting
  - impurity sourcing
- Caused by excessive v_{inj}
  - v_{inj} related to injector & main chamber fueling as well as I_{inj} demand
  - double layer physics due to density gradient between arc and main chamber
- Use ML to predict cathode spots before full initiation
  - power supply behavior
  - visible cathode spot detector
  - early power supply shut down to avoid electrode damage
  - requires data labeling of injector and time of spot initiation

LHI extracted electron beam



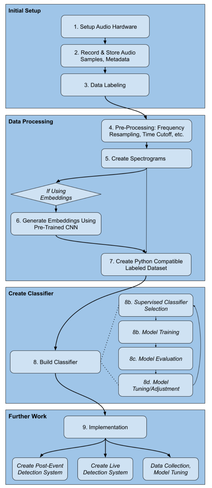
Cathode spots cause a significant and abrupt drop in V_{inj}



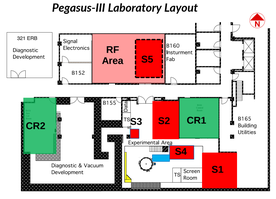
Audio Fault Monitoring

- Goal is to use audio monitoring to track off-normal events in experimental hall
  - localize event
  - classify event
  - potential mitigating actions
- Start with audio during discharge
  - record individual 'normal' sounds
  - can move to continuous monitoring

Proposed Flow Chart



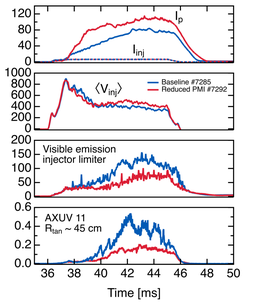
Pegasus-III Laboratory Layout



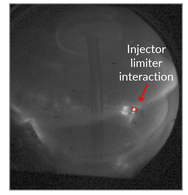
PMI Mitigation

- PF programming constrained by operating space
  - low PF at start for relaxation
  - ramp with I_p for radial force balance
  - PF induction drives more I_p
  - too much PF leads to injector decoupling
  - too little PF leads to limiter interaction
- Ip bifurcation related to local limiter interaction
  - identical shot programming
  - bifurcation correlates with interaction on visible image
- Use ML to determine features correlated with bifurcation
  - actual field vs. control request
  - base pressure
  - impurities
  - ?

Lower PMI leads to higher I_p



Fast camera image



Summary

- Pegasus-III data is being prepared for use in ML projects
  - initial work focused on getting calibrated data to accessible tree with appropriate metadata
  - accessible to collaborators
- Several potential ML projects are being developed for Pegasus-III
  - cathode spot detection/suppression
  - audio fault monitoring in experimental hall
  - PMI mitigation via radial position control
- Next steps
  - finalize data preparation & normalization
  - train/tune models
  - evaluate models for each application

References: [1] https://crea-psfc.github.io/open-fair-fusion/;

For More information,