Research Report
ICRR Inter-University Research Program 2020

Research Subject: New Photogrammetry Calibration and Machine Learning (ML) Event Reconstruction for Super-Kamiokande and Hyper-Kamiokande
Principal Investigator: Patrick de Perio
Participating Researchers: Nick Prouse
Summary of Research Result: We have continued to optimize the water Cherenkov machine learning (WatChMaL) platform to improve performance, facilitate new models and architectures, and produce exploratory data analyses and benchmarking to the existing traditional reconstruction algorithm (fiTQun). Comparable or better performance was demonstrated in electron/muon classification, as well as non-negligible power in separating electron/gamma in the IWCD. Application to Super-Kamiokande (SK) and Hyper-K Intermediate Water Cherenkov Detector (IWCD) neutrino Monte Carlos (MCs) has begun, for eventual adoption to official analyses. A first version of the Generative Adversarial Network (GAN) was trained to be able to mimic true simulated events, towards the mitigation of data/MC mis-modeling. Several Graph Neural Nets (GNNs) and multi-layer perceptrons (MLPs) were implemented to tackle neutron/electron/noise discrimination, to be tested on real SK data and compared to existing MLP and NN techniques. A new spherical convolution NN has been tested on SK supernova (SN) simulations to speed-up SN direction finding for the global SN detection effort, with optimization and deployment in progress. Research and development on panoptic segmentation algorithms has begun for improving multi-ring reconstruction and multi-vertex (pile-up) reconstruction in Hyper-K's IWCD. Photogrammetry data was taken during the last SK tank open work in February 2020, an extremely rare opportunity granted by the request to monitor critical Water Team upgrades for SK-Gd. For this campaign, an underwater remote operated vehicle (ROV) or drone was purchased, as well as equipment for backup GoPro cameras, with last year's ICRR grant. The drone's camera and backup cameras were calibrated underwater in a pool for precise undistortion of the photos in analysis later. The PI and postdoc (Nick Prouse) were trained to safely pilot the drone in the pool to prepare for deployment in SK. After the successful drone monitoring of the Water Team upgrades, over 12000 photos of the inside of the SK detector were taken. A preliminary photogrammetry analysis was able to reconstruct the PMT positions in a small section of the detector, precisely reproducing expected features such as the distance and angle between PMTs, as well as between the mounting bolts for each PMT. A simulation of the photogrammetry system/analysis was also developed to be able to compare to the real analysis and estimate systematic errors. The analysis is being improved to automate the feature recognition procedure and be able to apply to the entire photo set to precisely reconstruct the geometry of the whole SK detector. In parallel, work is ongoing to design and optimize the fixed camera systems for the IWCD, its prototype Water Cherenkov Test Experiment (WCTE), and the Hyper-K far detector, significantly benefiting from the above experience and developments in SK. About 40% of this year's grant was spent on 1) shipping the above photogrammetry

equipment to Canada and 2) purchasing new cameras for a HK PMT support structure mockup test in Kamioka. For 1), we are planning to continue calibrating the cameras, especially as a function of pressure (which can distort the optics) to improve the precision of the analysis and resulting measurements in SK. For 2), we are currently synergizing with the PMT and water group to understand water flow and temperature variations around the PMTs. Eventually, we will then use the mockup to test photogrammetry performance with different cameras and lighting systems, photographing various targets on the support structure to inform the design of IWCD, WCTE, and Hyper-K. The remaining funds have been requested for carry-over due to the pandemic travel restrictions.

There have been no publications this fiscal year as both machine learning and photogrammetry work have entered deeper stages of research and development that will require increasing amounts of analysis, scrutiny, and approval from both the Hyper-K and Super-K collaborations to publicize results.

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