

# Research Report

## ICRR Inter-University Research Program 2021

Research Subject: New Photogrammetry Calibration and Machine Learning (ML) Event Reconstruction for Super-Kamiokande and Hyper-Kamiokande

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### Summary of Research Result :

There has been significant progress in the water Cherenkov machine learning (WatChMaL) consortium in implementing new models and architectures, validation, and benchmarking to existing traditional reconstruction algorithms, and application to physics analyses:

1. The ResNet classification model was applied to the Hyper-Kamiokande (HK) Intermediate Water Cherenkov Detector (IWCD) beam neutrino Monte Carlo (MC) and showed superior electron/muon discrimination and hints of electron/gamma separation, which continues to be investigated and improved.
2. The data pre-processing pipeline for the HK far detector has been developed and PointNet is now being tested with electron/muon/ $\pi^0$ /gamma particle guns in the hybrid (50-cm PMT & multi-PMT) detector geometry.
3. The data pre-processing pipeline for Super-Kamiokande (SK) have been written for the low energy (LowE) and high energy (HE) analyses.
4. A first application of the ResNet (and a new boosted decision tree) to the LowE solar neutrino analysis shows potential for significantly higher background rejection compared to the traditional selection criteria.
5. The spherical convolution neural network (HEALPix fitter) shows significant improvement in supernova (SN) direction reconstruction time (~seconds) for the SK SNWatch program.
6. The Graph Neural Net (GNN) project has completed an initial result showing neutron/electron discrimination in IWCD and a publication is near submission.

7. A first implementation of panoptic segmentation algorithms was completed, showing the ability to separate rings in neutral pion events in IWCD, towards improving multi-ring and multi-vertex (pile-up) reconstruction.

This will be the final report on ML, as the next years' program will focus on photogrammetry only, which used all the funding in previous years.

Precious photogrammetry data was taken during the last SK tank open work in February 2020. This was a rare opportunity granted after a synergistic request to use an underwater remote operated vehicle to monitor critical water system upgrades for SK-Gd. An initial version of PMT feature detection using traditional image processing and ML semantic segmentation have been developed. These features were then labeled with a custom semi-automatic algorithm specific to the SK super-module structure to ensure the correct PMT is identified in each photo. Geometry reconstruction code was then applied to a set of photos from the ROV traversing horizontally around the detector barrel. This resulted in the first underwater reconstruction of PMT positions around a small ring (5-6 rows) of SK, showing no deviation from the design geometry within current measurement uncertainties, which contribute to a spread in deviation from design of 1.3 (4.2) cm in the tangential (radial) direction. Work is ongoing to automate this process for the entire detector, reduce the uncertainties, and apply the results to the SK detector simulation.

In parallel, the design, procurement, and production of the fixed and deployed camera systems for HK, IWCD, and its prototype Water Cherenkov Test Experiment (WCTE) at CERN, is progressing on schedule. A prototype of the underwater housing for the consumer-grade camera has been produced and is being testing now with new optical calibration hardware and procedures. An underwater red lamp was purchased with this grant to test its feasibility with online PMTs. Integration designs for the WCTE and its calibration deployment system are ongoing. The experience, analysis and simulation software developed from the SK photogrammetry campaign have been extremely beneficial to this work.

There have been no publications this fiscal year as both machine learning and photogrammetry work are still in the research and development stage that require increasing amounts of analysis, scrutiny, and approval from both the Hyper-K and Super-K collaborations to publicize results. However, ~8 conference and workshop presentations were given on the photogrammetry process and status.

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