Master of Science in Engineering – Master Thesis

Deep Learning in Real Time Liquid Level Detection

Performance Comparison of Classical DSP Algorithm with Neural Networks

Application and Measurement Principle

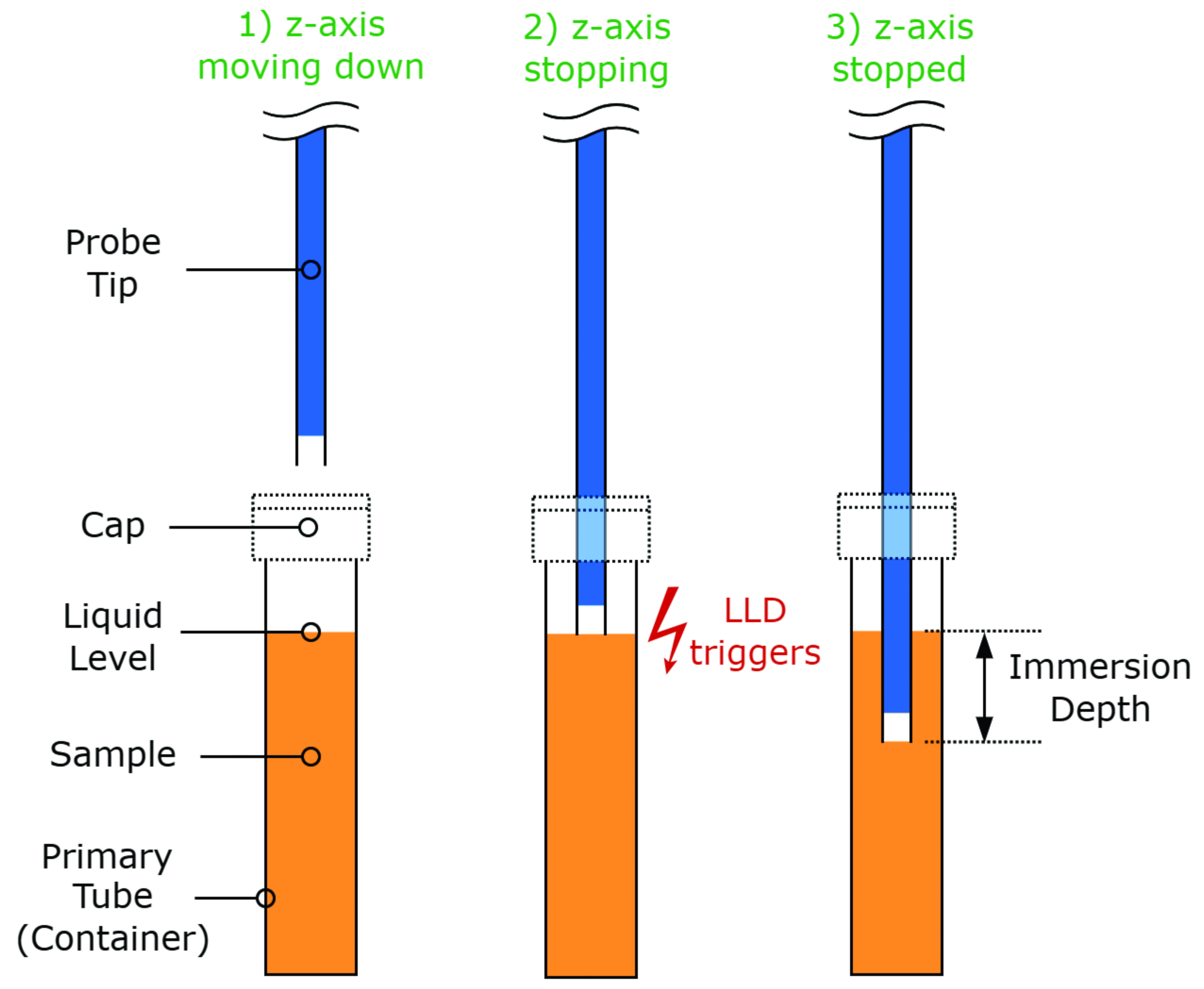

Figure 1: Main Purpose of Liquid Level Detection

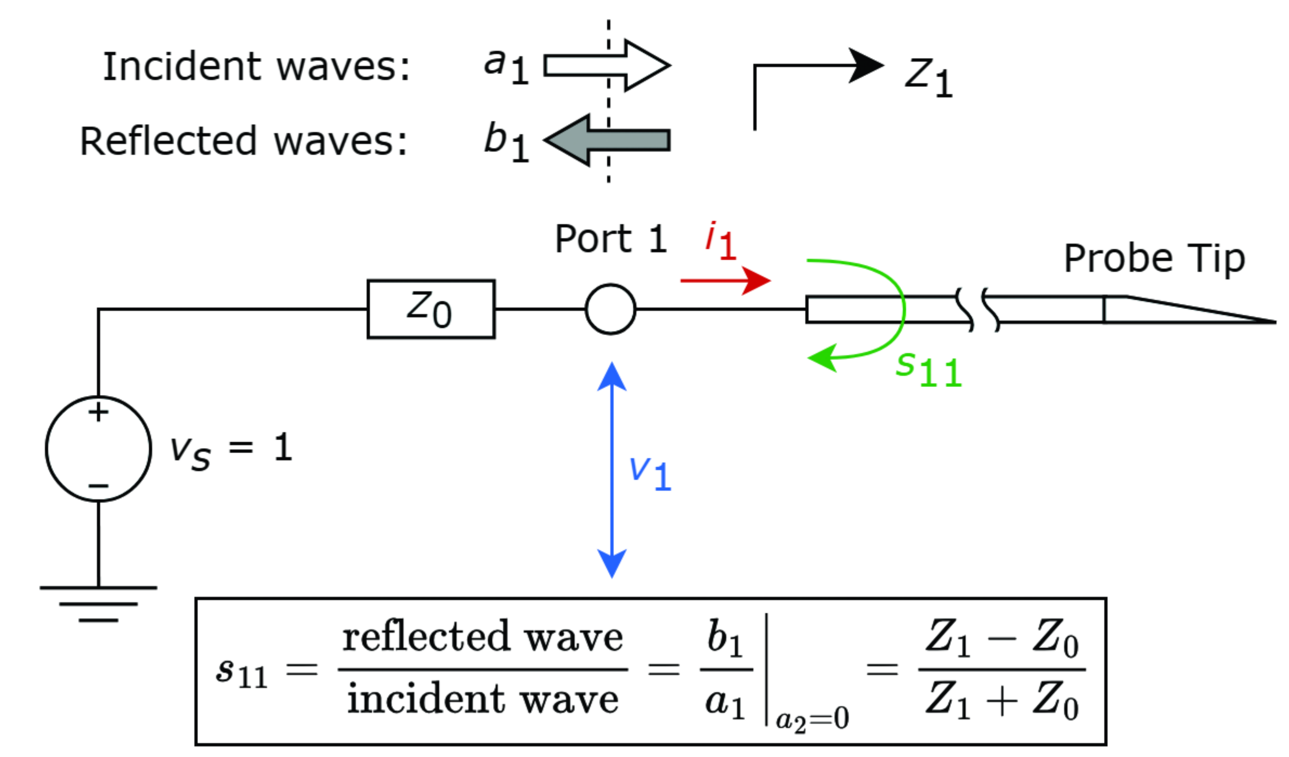

Figure 2: Scattering Parameter Measurement Principle

Container Types and Results

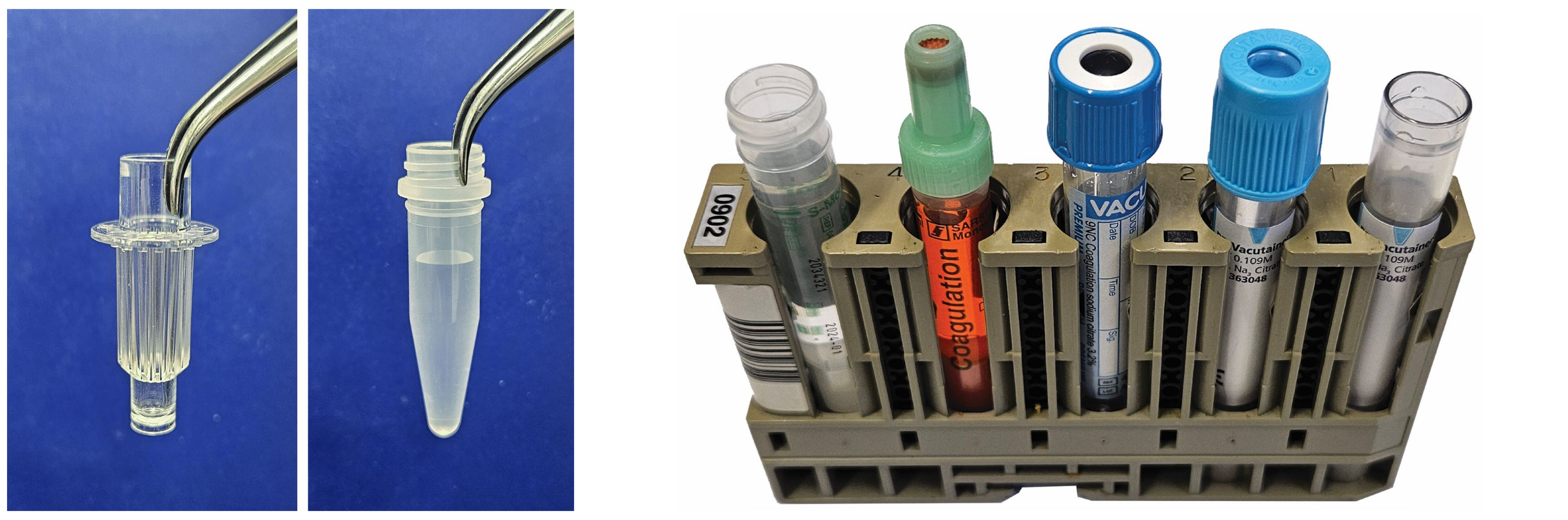

Figure 3: Two types of cups and different primary tubes placed in a rack

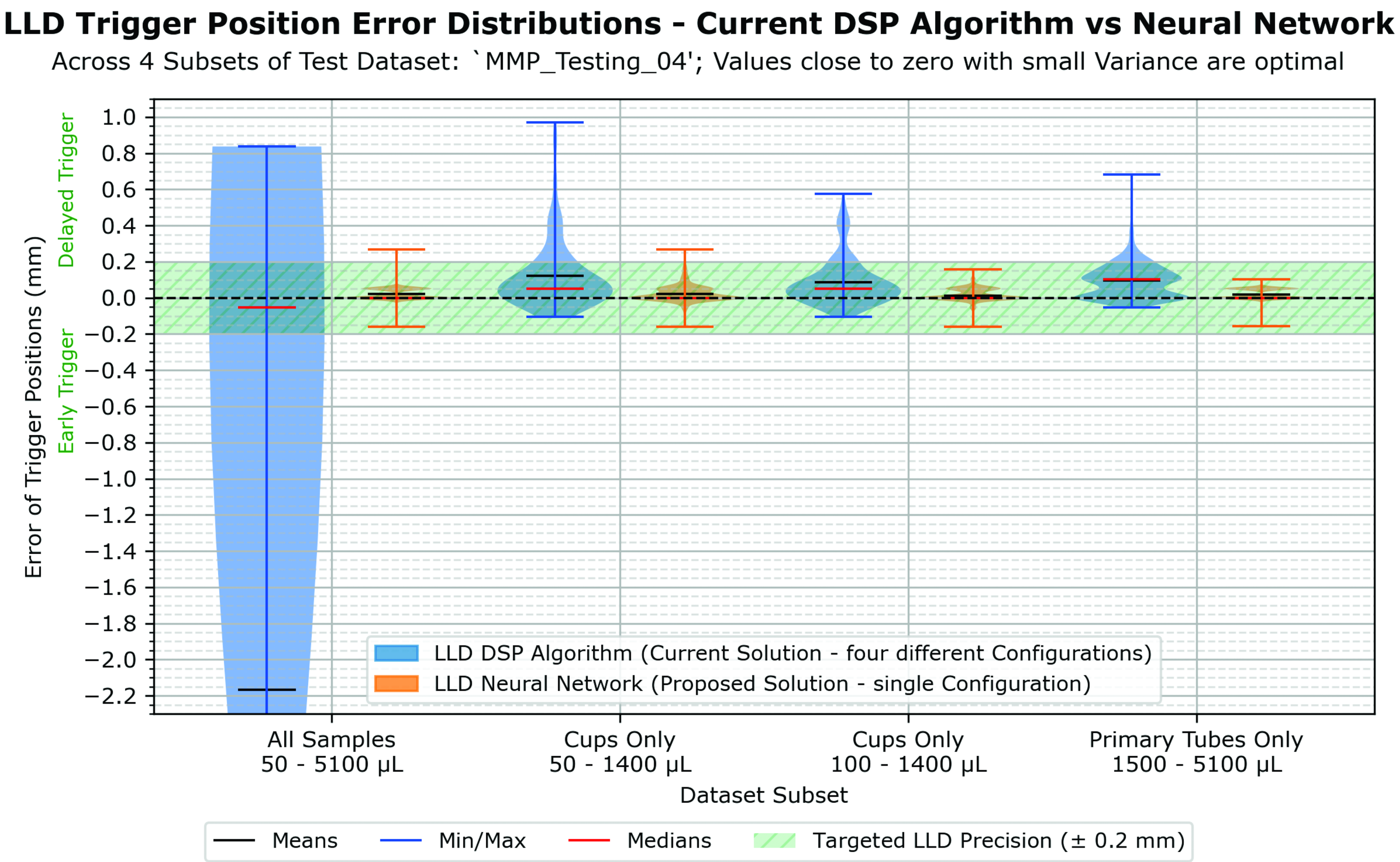

Figure 4: Performance of the DSP Algorithm vs. the best Neural Network

Project Task

To enable reliable and consistent results in diagnostic tests, high accuracy and precision in liquid volume handling are crucial. One aspect is to precisely determine the liquid level in order to reach a configured immersion depth as shown in Figure 1. The raw data from the measurement electronics is evaluated in real-time to determine the point in time when the probe tip touches the liquid surface. The industrial partner refers to this technology as "Liquid Level Detection" (LLD). In a specialization project prior to this thesis, a novel approach for the measurement electronics was developed. It is based on the measurement of the probe tip's reflection coefficient (s_{11}-parameter) described in Figure 2. This thesis investigates the transition from classical Digital Signal Processing (DSP) to real-time deep learning for LLD. The performance of the trained Neural Networks (NNs) must be evaluated and compared to the currently used classical DSP algorithm. Additionally, it must be assessed if and how the NN can be integrated into the full system to enable edge-based inference.

Concept

Various NN model architectures are trained using a grid search strategy on a purpose-built dataset. The evaluation and selection process balances detection precision and accuracy with the computational efficiency required for real-time execution. Concurrently, a grid search is performed to find the optimal DSP algorithm configurations, establishing a performance baseline against which the NNs are benchmarked.

Results

The proposed NN model demonstrates robust generalization properties. It maintains high trigger accuracy and precision across a large volume range from 50 to 5100 µL. The test dataset includes various fluids and container types such as cups and primary tubes (see Figure 3). Unlike the NN, the DSP LLD algorithm requires multiple, container-specific configurations and yet still fails to match the NN's performance. It is not possible to find a single configuration that performs equally well as the NN with its universal configuration. To evaluate edge-based inference, the NN was ported to C code in order to run it on an Arm Cortex®-M4 core. Several optimizations led to inference times of under 10 µs, allowing real-time data processing on resource-constrained hardware. This work proves that deep learning represents a promising alternative to classical DSP algorithms and that NNs have the potential to improve the accuracy and precision of real-time LLD.

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