Development of FPGA Processing Unit for Quantum Receiver Enhanced by Adaptive Learning

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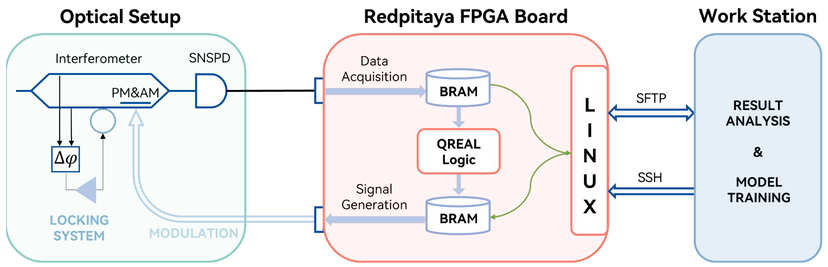
Introduction and Background

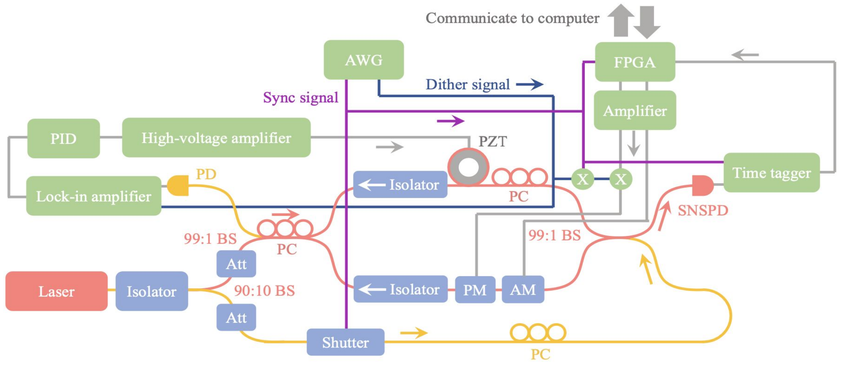
Quantum information science (QIS) has revolutionized communication, sensing, and computing capabilities by leveraging the unique properties of quantum states. Quantum receivers play a pivotal role in improving performance by enabling enhanced information processing tasks such as quantum-state discrimination and parameter estimation. Traditional analytical approaches to Quantum Receivers struggle to adapt to diverse operational conditions and are quickly overwhelmed by noise in practical scenarios. To address this challenge, we present the Quantum Receiver Enhanced by Adaptive Learning (QREAL) architecture. QREAL leverages reinforcement learning to adaptively design quantum receivers capable of tackling a wide range of QIP problems and environmental conditions. Our results showcase the ability of QREAL to adapt to noise and imperfections, thereby outperforming conventional quantum receivers and classical approaches.

Methods

• System Architecture



The receiver was developed in two parts. The quantum hardware system was developed using a phase-locking interferometer and a superconducting nanowire single-photon detector (SNSPD). The FPGA phase modulation controller was developed in Verilog using Xilinx Vivado and deployed onto a RedPitaya board.

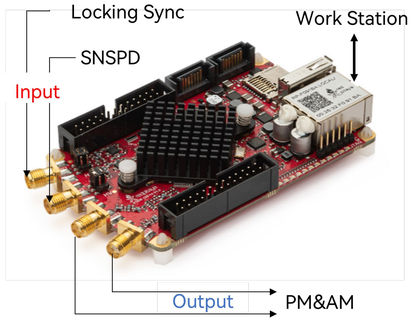


Methods

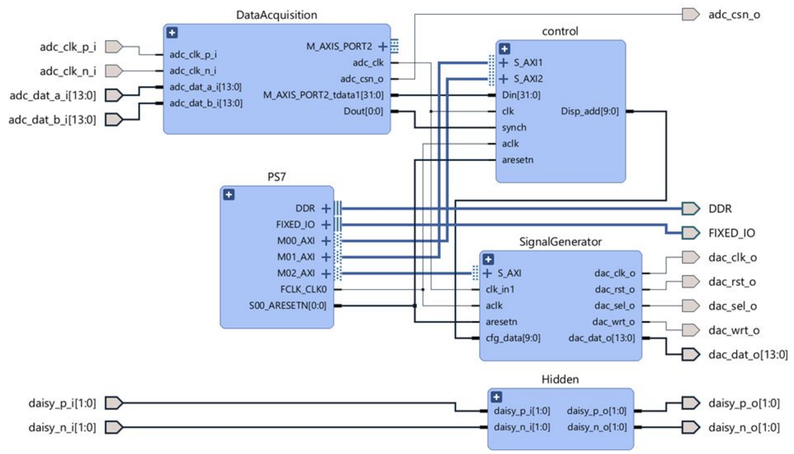
• FPGA Control System

➔ Red Pitaya 125-14 Board
- ◆ FPGA + Linux
- ◆ SMA inputs & outputs
- ◆ 125MS/s - 14 bit ADC

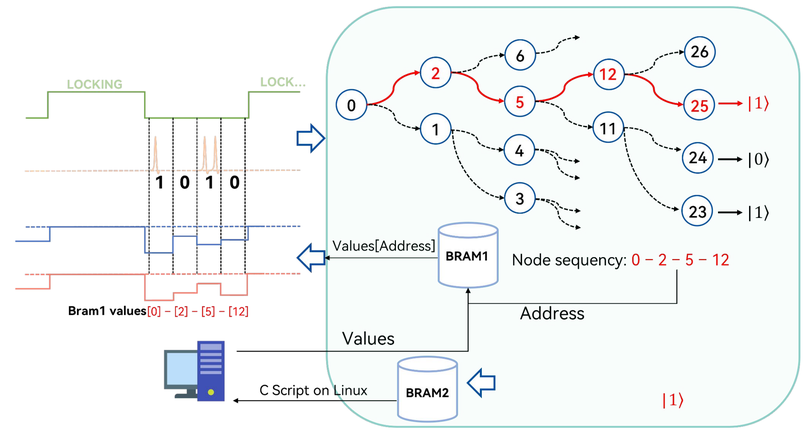
➔ Programmed in Verilog using Xilinx Vivado
- ◆ Incorporates open-source cores
- ◆ Communicates to formulator using custom C scripts on Linux



➔ Hierarchical Block Diagram
- ◆ Detects number of photons detected from SNSPD with custom Verilog Module and stores measurement to BRAM with open-source AXI BRAM cores

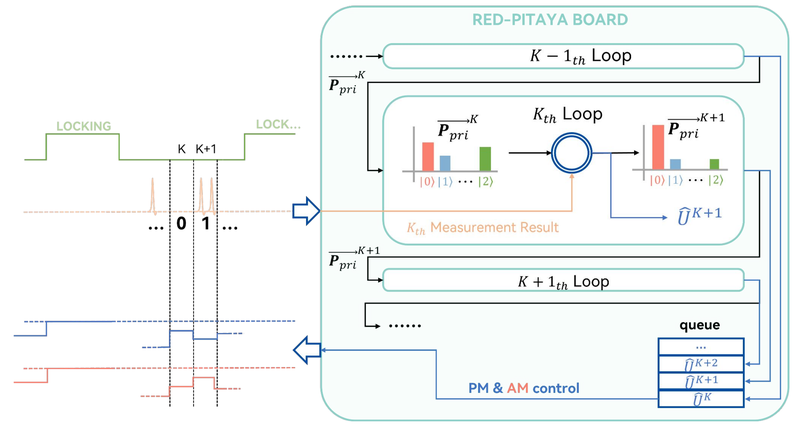


• QREAL Decision Tree



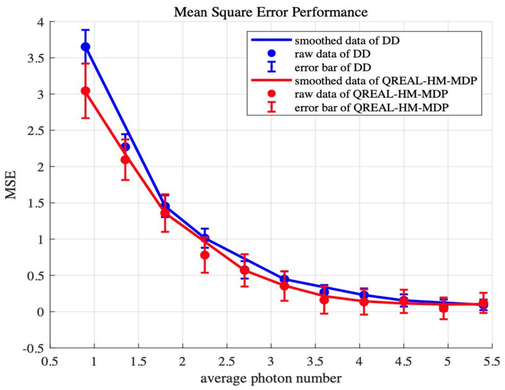
Methods

• QREAL-Markov Model

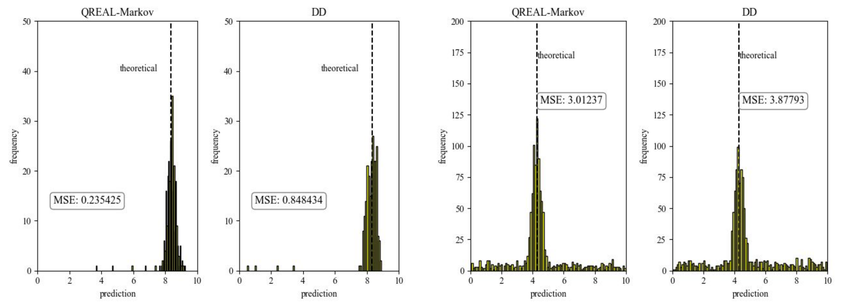


Results

➔ BPSK Decoding
- ◆ QREAL-Markov model showed improved performance compared with QREAL decision tree
- ◆ Best performance observed when combining QREAL decision tree and Markov Model



➔ Estimating pulse arrival time with QREAL-Markov
- ◆ 10 time bins, 1 photon per pulse



References

Cui, C., Horrocks, W., Hao, S. *et al.* Quantum receiver enhanced by adaptive learning. *Light Sci Appl* **11**, 344 (2022). https://doi.org/10.1038/s41377-022-01039-5