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# Quantum Sensing

PYNQ-based Portable Nuclear Magnetic Resonance Spectrometer Powered by Deep Learning from AMD Xilinx

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## Indroduction and Applications

NMR (Nuclear Magnetic Resonance) is a powerful quantum sensing technique that utilizes the quantum state changes of atomic nuclei in an applied magnetic field to probe, analyze, and image the structure and properties of a sample.

NMR Spectroscopy aids in the **medical field** for the early disease detection and characterization by analyzing tissues and bodily fluids. Additionally, it contributes to drug development by investigating drug-target interactions.

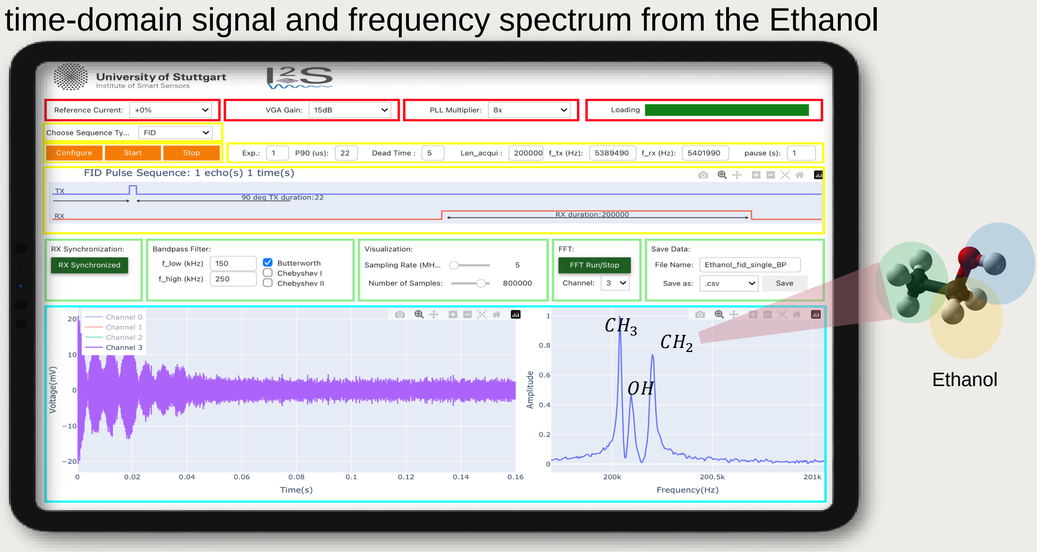
NMR Spectroscopy has widespread applications in the **chemical industry**. It is used for analyzing compound structures, identifying purity, studying reaction kinetics, and exploring metabolic processes. NMR Spectroscopy plays a vital role in the development of new materials, quality control, and process optimization. Additionally, it finds extensive use in areas such as catalyst research and polymer analysis.

NMR Spectroscopy is extensively used for **food product control**, analyzing composition, quality, and safety. It ensures accurate analysis of nutritional components, additives, contaminants, and authenticity verification. This non-destructive technique ensures food quality, compliance, and detects fraud, protecting consumer rights and industry reputation.

NMR Spectroscopy is applied in **quantum computing**, utilizing nuclear spins as qubits. It offers precise qubit control, measurement, and some fault tolerance. While limited in scalability, it provides a platform for experimental and algorithmic validation, contributing to the advancement of quantum computing technology.

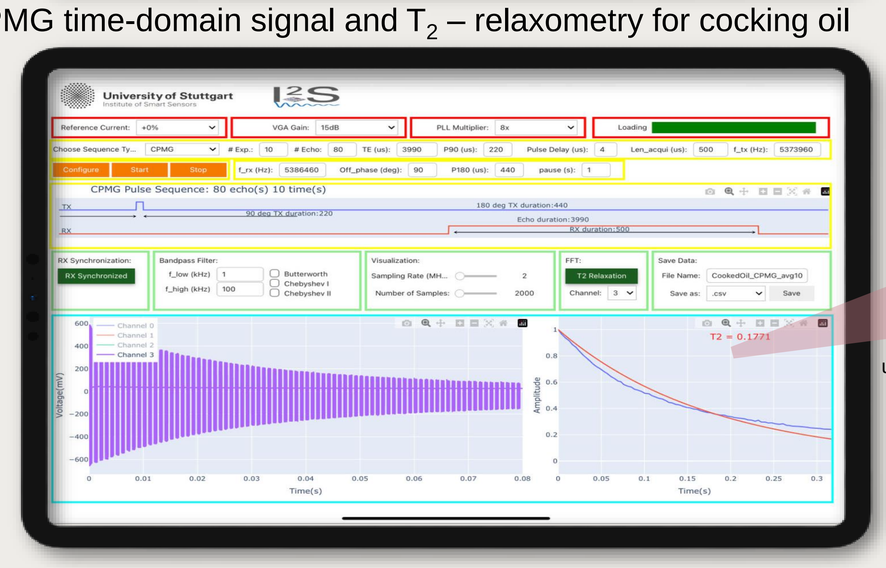
## Experiments Result Illustration on Ipad*

FID time-domain signal and frequency spectrum from the Ethanol




Ethanol

CPMG time-domain signal and $T_2$ – relaxometry for cocking oil



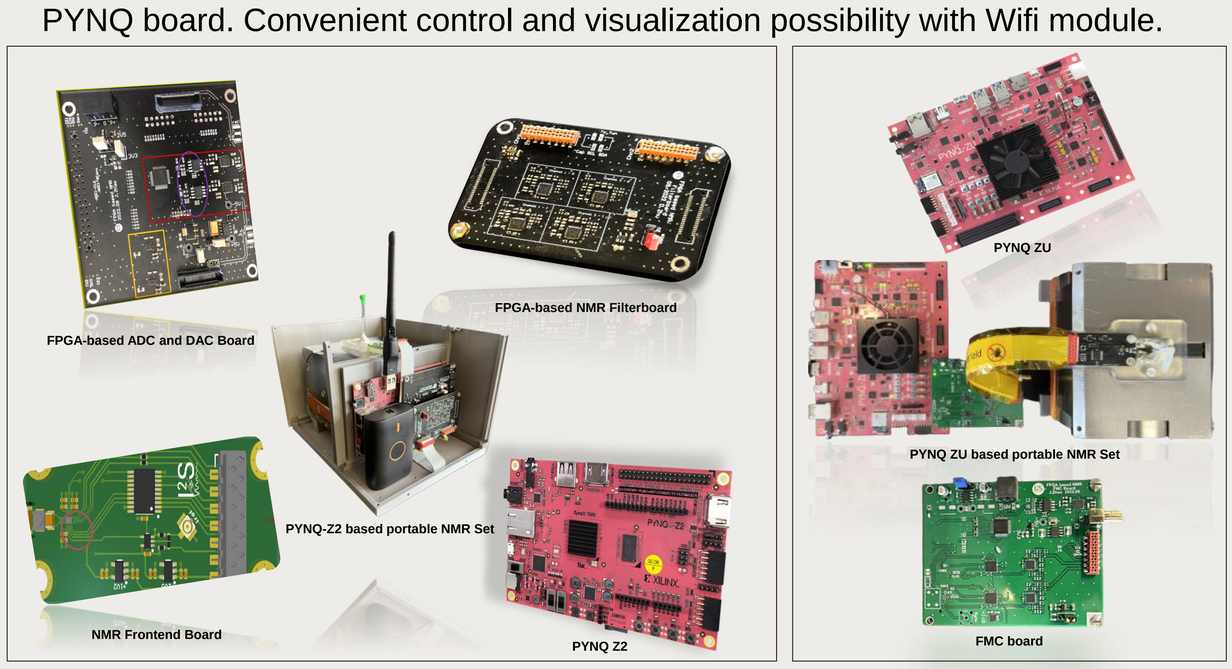

used and fresh oil

* Please refer to the experimental section for more information

## System Configuration

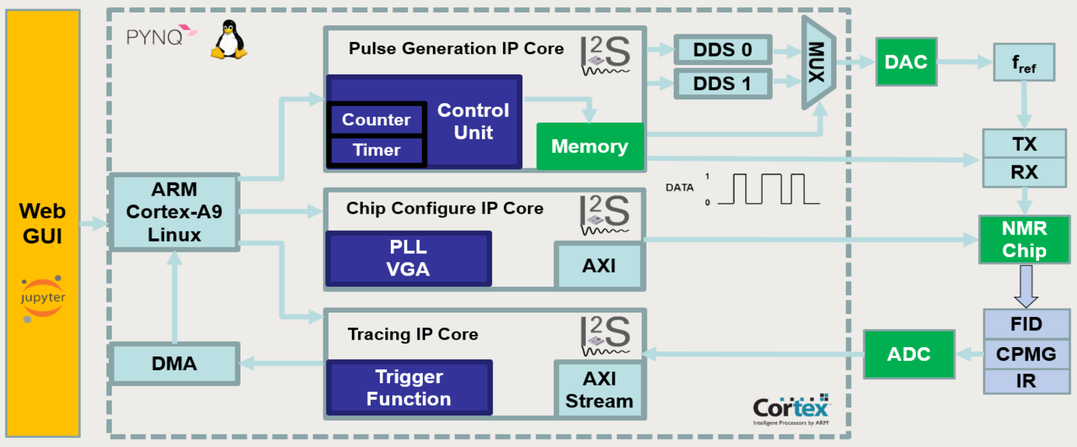
- Hardware Components

Custom-designed PCB boards for portable NMR experiments are mounted on PYNQ board. Convenient control and visualization possibility with Wifi module.




- Software Architecture

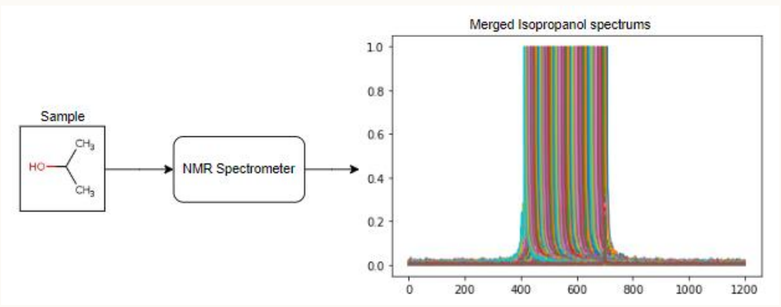
High-speed data flow enables real-time data collection, transmission, visualization, storage and processing, forming a robust data ecosystem powered by PYNQ.



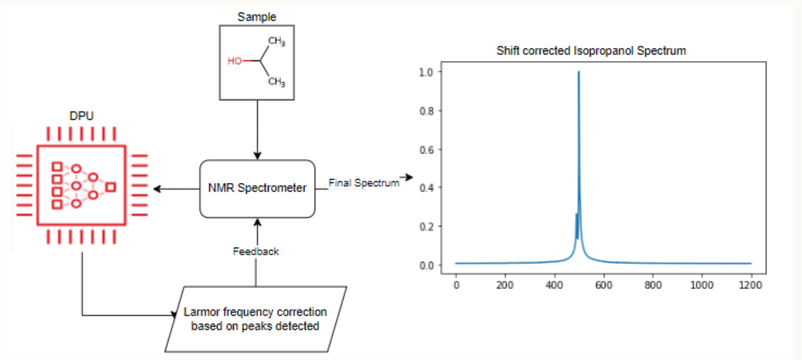

## Deep Learning Based Material Analysis

AMD's Xilinx Deep Learning Unit will provide significant assistance for material spectrum identification in NMR spectroscopy. Here, we apply it in spectrum detection and in the spectral correction of the transmission frequency of the ASIC, to ensure signals resulting from spin are perfectly averaged to reduce noise. We also continually adjust based on feedback from the deep learning unit to ensure samples are excited at the correct Larmor frequency.

Without AI based correction

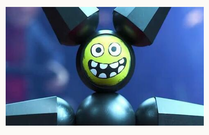



With AI based Larmor frequency correction




## Conclusion

In our experiments, AMD's Xilinx ZYNQ series FPGA perfectly met the demands of high-performance computing and control systems for quantum sensing. In the future, if our team can secure funding support, we believe our NMR spectroscopy based on a distributed AI system will make significant contributions to medicine, the chemical industry, food quality control, and quantum computing.



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