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A Compact, Cost Efficient, Modular, Intelligent Ultrasound Sensor Platform

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Summary:
We developed and evaluated a new modular concept for a modern compact ultrasound sensor platform. The hardware is designed as an inexpensive, matchbox-sized set of components that can be easily combined and configured for a wide range of applications including mobile and distributed technical or wearable biomedical ultrasound. The modular concept and flexible software architecture allows the adaptation to new applications with a short time to market and will be applied in distributed sensor networks including edge-AI based processing in the future.

Keywords: modular ultrasound device, artificial intelligence, networked system, flexible handheld device, cost efficient

Background, Motivation an Objective

Ultrasound (US) measurement technology is comparatively inexpensive, real-time capable, non-invasive and a flexible method used commercially in the medical and industrial applications. In both fields there is still great potential for application specific and dedicated ultrasound sensor systems including an automated signal analysis and classification using artificial intelligence. Using ultrasound measurements, material properties can be examined non-destructively as well as flow speeds, distances or fill levels of solids or liquids. Based on the objects being examined, application-specific solutions with adapted ultrasound transducers, transmit/receive electronics and signal analysis must be developed to match the individual requirements. Therefore, ultrasound systems with different levels of integration and complexity are often realized as a dedicated solution tailored to a single or only a few applications. This circumstance makes these systems inflexible to match new requirements for slightly adapted use-cases or new product variations, results in high development costs and a relatively long time-to-market when transferring ultrasound technology to new fields of application. We developed a flexible ultrasound system and software architecture based with a modular design to realize innovative solutions and products in a wide range of applications with a low time-to-market.

Materials and Method

Our single channel system “SonoOne” is designed to be cost-efficient and modular. Based on a set of many different modules, a sensor system can be set up and configured depending on the application and requirements. A basic system configuration consists of 4 modules (see figure1):

1. A basic ultrasound electronics module for generation of US-transmission signals and digitization
2. A Communication interface module including wired (USB, Serial, …) and wireless data transfer via WiFi to mobile devices or a central server infrastructure.
3. Power supply module for the common supply of low voltages.
4. A High voltage power supply module for the generation of transmission signals (bipolar excitation of the transducer using a tri-state transmit pulser that can be arbitrary programmed allowing coded excitation).

The size of each PCB module is 50mm x 30mm. The modules can be flexibly configured via standardized hardware and software interfaces. In addition to those standard modules, the modular stacked design allows the usage of application specific extensions. An OLED display stack has been developed to be used on top of the stack to show important status information or measurement results. Another extension module allows a battery-powered and mobile usage by integrating a Li-Ion battery module and a charging circuit. Future modules can extend the SonoOne module stack by data storage modules integrating flash memory or storage cards to record data during long-term measurements or hybrid sensor modules integrating other measurement modalities.

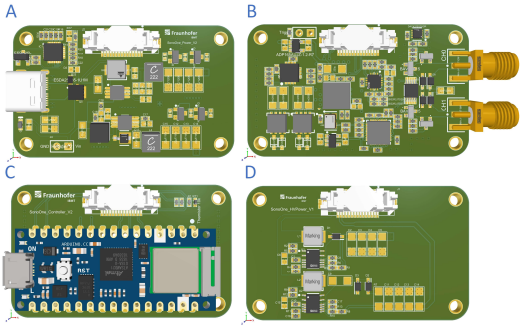

Fig. 1. 3D PCB Layout of the 4 basic modules (low voltage supply (A), US-module (B), control unit (C), high voltage supply (D))

Multiple of those ultrasound system stacks will be combined to form an intelligent sensor network via a wireless interface and data will be shared between the sensor systems. Currently, the communication module implements a standardized communication protocol for data transfer to a mobile device (i.e. a laptop) and the SonoOne hardware to connecting to a local WiFi infrastructure. This way, SonoOne is prepared to realize a distributed sensor network for larger scale measurement tasks in industrial setups.
The specification of the basic system configuration is listed below.

Tab. 1: System specification

power supply	5 VDC		Rx gain	0-50 dB
Tx voltage	up to 200 Vpp		Rx sampling rate	40 MHz / 80 MHz
Tx clock	80 MHz		ADC resolution	12 bit
Tx frequency	20 kHz - 10 MHz		samples per measurement	6600

Evaluation of the System

For evaluation of the system, several integration concepts including custom housing and mounting options for various applications (object detection in water, air or liquid flow measurements) have been realized. The basic configuration achieves an interactive wireless communication with repetition rate of approx. 25 Hz (using 2048 samples per measurement) transferring the digitized ultrasound raw data via WiFi to the connected PC/backend where storage and analysis with additional processing of the data can been performed. In combination with custom in-house developed wedge transducers, the flow of water in a pipe could be measured with high accuracy. Compared to a commercially available system, a flow of 500 l/min could be detected with an accuracy matching the commercial magnetic-inductive flow meter system (KROHNE Altometer SC 100 AS). Another demonstrator integrated a mobile air-coupled ultrasound measurement system using commercial 40 kHz ultrasound transducer capsules that provides not only distance information but also raw high-frequency ultrasound signals for further analysis in new applications.

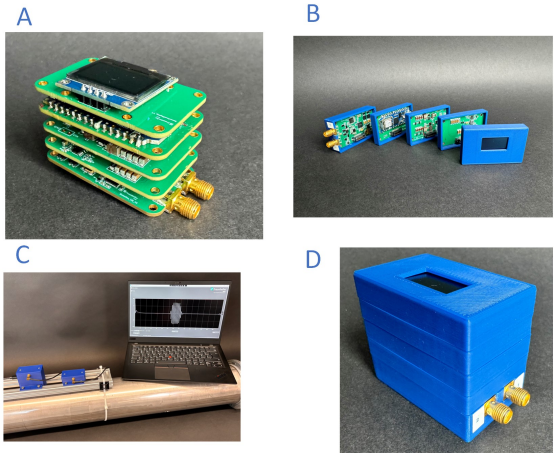

Fig. 2. Assembly of different prototypes (stack of all 5 developed modules (A), integrated in a 3D printed housing (B), integrated together with a Li-Ion battery (D), combined with in house developed transducers for clamp on flow measurements (C)

Results

The implementation of a modular circuit board concept into an application specific measuring system for gaseous, liquid and solid media was successfully realized and evaluated. A new technology platform for industrial applications has been implemented and can be adapted / extended easily. The developed modules are a basis for new product development in the context of cost-effective, intelligent and networked medical and industrial products.

Outlook

A main advantage of the modularity is that future technological leaps in individual components (efficient energy storage, new radio standards, new materials for ultrasonic sensors, improved manufacturing technologies in electronics and enhanced analysis algorithms) can be directly exploited by replacing the corresponding module without having to redesign the entire electronic unit, thus forming the basis for completely new applications, especially in the area of industry, medicine or sports. Automated intelligent evaluation processes can be carried out both in a cloud network or as Edge AI with integrated data processing capacity.

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