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Design and Implementation of an Ultrasonic Device Prototype with Arduino

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Annotation: Sonography is versatile diagnostic approach used for examining patients. In physics, the term 'ultrasound' applies to all caustic energy (longitudinal, mechanical wave) with frequency above the audible range of human hearing. which its range 20Hz-20KHz and the ultrasound frequency its greater than 20KHz (it's not different from normal sound wave in physical properties except human cannot hear it). this project provides an examination of the patient by using ultrasound technology based on uses a small probe called a transducer and using 5MHz transducer sensor. Ultrasound gel is placed directly on the part of the body that is to be examined and the transducer is then applied. High-frequency sound waves travel from the probe through the gel into the body. The transducer probe collects the sounds waves that bounce back to create an image which can then be viewed in real-time via a LCD TFT screen on arduino due microcontroller. By programming the microcontroller and its code attached to Annex No.1 at the end of the research.

Keywords: Ultrasound imaging, Arduino Due, transducer sensor, low-cost diagnostics, biomedical engineering, open-source hardware.

1. Introduction

Ultrasound imaging has evolved since the first ultrasound machine appeared. The first devices were using single-sensor (transducers) techniques, coupled with mechanical scanning [1]. The architecture of such systems, as shown in Fig.1, is well-known and formed the basis of ultra -sound imaging Mechanical scanning has its limitation, but also its strengths: a single signal channel, linked to a single sensor, means that the corresponding electronics are simplified, and the cost is reduced. Moreover, with progress made in different technical fields, mechanical probes are seen on the market again. Search in academic literature, and open-electronics resources, yielded little to no documentation of previous research to rebuild these mechanical ultrasound imaging devices. To the best of the author's knowledge, there are no open-source hardware designs nor electronics accessible online for the analog-processing component. To bridge this gap, this work provides modules to the community to understand and recreate the electronic core of an ultrasound device.

This ultrasound kit consists of several modules mainly built from easily available components. Two electronic modules were specifically designed to provide the basic development kit. These two modules, called the Ultrasound Imaging Analog Core (UIAC), as shown in Fig.1 above are:

1. **The Transducer pulse Module (TPM):** designed to provide a precise high-voltage pulse, necessary to excite the sensor, while remaining robust enough to be controlled by an Arduino;
2. **The Analog Processing Module (APM):** designed to correctly process the raw ultrasound electric signal, while easily exposing all intermediary signals, and exposing a digital output to the user.

Ultrasound is one of the most widely used imaging tools for non-destructive testing (NDT) and non-invasive medical diagnosis. Since its beginnings in the 1950s, ultrasound imaging research has led to innovations such as new sensors, signal processing, and device development. More than fifty years later, the field continues to evolve, supported by advances in electronics and digital devices. However, the field is still being researched regarding open source experimental devices. An open, flexible, and cost-effective platform is still needed for many basic medical applications and tests. A platform of this kind will support the efforts of researchers, makers and device developers in accelerating ultrasound. Research and development the objective of this review is to identify the literature relevant to the Understanding, design and operation of simple ultrasound devices and to present this body of knowledge in an accessible format to ultrasound system designers. It also provides a summary of current ultrasound research to. Familiarize readers with trends of interest we capture design and usage considerations from both classic and Modern tools. We cover both NDT and medical applications, starting with a design context review, followed by a review of existing structures and analog building blocks, followed by a survey of the digital options available to support. And complement devices.

1.2 Overall Implementation and design using echoes for imaging

Ultrasounds, high-frequency sound waves, are used in medical applications for both diagnosis and treatment of patients. Their frequencies can vary from 2 to approximately 15 MHz for regular imaging, where in some cases higher frequencies are used for a finer surface imaging. The ultrasound waves originate from the mechanical oscillations of a crystal in a transducer, excited by electrical pulses, also known as the piezoelectric effect. These pulses of sound are emitted from the transducer, propagate through the different media being imaged, and then return to the transducer as "reflected echoes" of an interface, as shown in Fig.2. These reflected echoes are converted back into electrical signals by the transducer and are further processed to form the final image. [2]

In general, these sound waves, like typical waves, are reflected at the interfaces between the tissues of different acoustic impedance (linked to the density of the medium), where the strength of the echo is proportional to the difference of the impedance. On the other hand, echoes are not produced if there is no acoustic difference, hence no impedance interface, between media. Homogeneous fluids thus seen as echo-free structures.

1.3 Sonography principal work

Sonography is a very important way in medicine to look inside the body. The principle is simple: A transmitter sends ultra-sonic-pulses. They spread out in the body, are being reflected by inner organs or bones and come back to the receiver.

1.4 Problem Statement

Detect tumors in certain areas of the body that don’t show up on X-rays. It’s also used to guide instruments during a biopsy in which a small amount of fluid or tissue needs to be removed and studied under a microscope. During that type of procedure, the doctor watches the ultrasound screen while moving a needle toward and into a tumor or growth.

1.5 Objectives and Scope of Study

Sonography is a significant way in medicine to look inside the body. The principle is simple: A transmitter sends ultrasonic pulses. They spread out in the body, are reflected by inner organs or bones, and return to the receiver. Ultrasound imaging uses sound waves to produce pictures of the inside of the body. It helps diagnose the causes of pain, swelling, and infection in the body's internal organs and to examine an unborn child (fetus) in pregnant women. In infants, doctors commonly use ultrasound to evaluate the brain, hips, and spine.

2.1 Ultrasound

Ultrasound, also known as ultrasound scanning or sonography, is a painless and harmless technique used to construct a visual representation of a person’s internal structures. As mentioned in the introduction, this technique uses high frequency sound waves which are transmitted to an object in the body using a probe that is placed on the patient’s skin. To facilitate the device’s ability to transmit and receive sound waves, an ultrasound gel is spread between the skin and the ultrasound transducer [3]. Ultrasound machines utilize a series of components that work in tandem to produce an image of the body’s organs or structures including the transducer probe that was briefly discussed in the introduction, a transducer pulse control, a central processing unit, display, keyboard/cursor, disk storage device, and printer.

As one of the most crucial pieces to these machines, the transducer probe is responsible for creating sound waves, projecting them and receiving echoes. The transducer uses the piezoelectric effect, which allows electricity to flow based on the potential that is created when a crystal is distorted and compressed. The reverse can be said to happen if you flow electricity through the crystals instead to control the frequency and duration of the transducer pulses, the transducer pulse controls give the operator domination over the amount of current being passed through the crystals [4].

Much like a personal computer, ultrasound systems utilize a central processing unit (CPU) to combine the multiple types of inputs being generated by the transducer probe. As the brain, the CPU is responsible for doing all the calculations needed to produce an image of the region of interest. In 2D imaging, multiple flat cross section images are taken and converted into electrical signals by the CPU. This method is the most common standard in the industry.

However, ultrasound machines are able to produce more than just 2D images. They can produce 3D images, 4D images as well as Doppler Ultrasounds [4]. To create the more complexed 3D images, the CPU has to combine positional data, which is retrieved from position sensors and snapshots taken by the probe. Once processed, the combination of information is presented in a 3D image of the area of interest and is displayed for the user to see. This type of ultrasound represents a more accurate picture of the area of interest. Similar to 3D ultrasounds, the 4D images utilize position to create a more comprehensive representation of the cross sectional area. In the fourth dimension, time is added, which creates the simulation of a moving picture. In this dimension, the CPU compiles multiple 3D images rapidly to create a moving image of the region of interest.

Lastly, Doppler ultrasounds are also used in the industry. Unlike the 2D, 3D, and 4D ultrasounds, Doppler is used in order to analyze blood flow rather than see structure. While it still uses high frequency waves, the Doppler ultrasound instead looks for the returning signal that has bounced off the blood cells. Since the blood cells are in motion, the signal sent and the signal reflected will be slightly different. Using this data, the CPU can then calculate the direction of movement and the velocity at which blood is moving [4].

2.1.1 Importance of this field

As mentioned in Section 2.1.1, ultrasound is used to create an image of internal body structures in human beings. Radiologists rely on diagnostic ultrasound scans to be able diagnose patients and determine specialized treatment. This type of ultrasound is commonly used in pregnancy cases for routine checks and to keep track of fetus growth. Aside from pregnancy, diagnostic ultrasound can also be used to image organs such as the heart, blood vessels, brain, etc.

Outside of diagnosis, functional and therapeutic (or interventional) ultrasound are also used in different cases. With functional ultrasound, physicians are able to use it to assist in varying cases. In electrography, ultrasound is used to find the stiffness of tissue which can help physicians determine whether an abnormality may be a tumor or not. In other situations, physicians may use functional ultrasound to help them perform more precise operations such as biopsies. In therapeutic ultrasound, the sound waves are used in targeting specific areas in the body in order to heat or break up damaged tissue.

2.2 Main Causes/Issues of Ultrasound Reproducibility

2.2.1 The use of ultrasounds without position sensors

Good quality ultrasound systems are relatively expensive and are not easily available across all demographics. Prices could be up to thousands of dollars for position sensors, and oftentimes you would need to buy in bulk. Position sensors in the medical field are not usually used with user interfaces in mind. They are usually used for special applications. Along with other tracking systems in an ultrasound device, it is difficult for all socioeconomic groups to have access to these devices [5].

2.2.2 Current Methods of Improving User Accuracy

There are different preventative measures that can be put in place to decrease human error and optimize accuracy in the field of ultrasonography. 3D Ultrasound devices give enhanced diagnostic capabilities to make it easier for less trained professionals to interpret different ultrasound images compared to a 2D ultrasound system device. The key to converting 2D images to 3D images, however, is sensing the orientation of the transducer relative to the ultrasound image being constructed [6]. This could also be obtained by a compilation of different 2D array scanners to build a 3D volumetric image. Different positioning systems can be used such as magnetic or optical trackers. However, these features are only exclusive to non-portable ultrasound devices. Optical fibers and sensors however, can be implemented into a portable ultrasound system without losing accuracy. This is done by having an attachment placed on a transducer handle which can help with user accuracy. For example, a mouse driver was used to extract position information from the sensor, recording the acceleration of the mouse driver. This was tested to have a high accuracy of 55mm movement. Different analytical methods are used by ultrasound technicians to identify the proper orientation of legions. There are how legions interact with their surrounding environment that could produce. This includes linear lines and delight reflections, as told to us by an ultrasound technician. [7]

2.3 Current Technology and Their Limitations

2.3.1 Embedded Sensor in Ultrasound Probe

The current gold standard of an ultrasound imaging sensor is an ultrasound probe with an embedded sensor, which was patented back in April 2003. A model of the transducer can be seen in Figure 2.1. The transducer probe consists of the position sensor and the array of discrete elements that transmit ultrasound waves and receive ultrasound waves reflecting from the subject area [6]. In this embodiment, the array of piezoelectric crystals is connected via array signal wires with a transducer probe cable The position sensor is made up of a unit for optically acquiring images of a surface of the subject area during operation, for acquiring information from said images, and for processing said information from the acquired images into positional information on the transducer probe relative to the subject area. The sensor is connected via position signal wires to the transducer probe cable [8].

The problems with this device is that the sensor is embedded inside the transducer. However, the team's position sensor is going to be attachable to the surface of the transducer probe. In addition, the sensor does not indicate whether the transducer is at the correct position, in which our group plans on resolving.

2.4 Ultrasound imaging

Ultrasound imaging, one of the most widely used diagnostic modalities, anchors the fields of medicine, physics, and engineering. In university classrooms, however, ultrasound imaging is often taught passively with a lack of practical element as the clinical machines are not easily available and there are very few alternative teaching tools available on the market. As part of an undergraduate student project, several researchers 'Xu Zhao, Jem Hebden, Rebecca Yerworth' have published an article in European Journal of Physics, which they talked about the developed a teaching toolkit featuring an inexpensive ultrasonic range finder to demonstrate the pulse-echo imaging process. The primary focus is the construction of equipment to enable known pedagogic principles (relating to active learning) to be applied to the subject area of ultrasound. Although operating at an acoustic frequency considerably lower than that employed clinically (and therefore achieving a much lower spatial resolution), the toolkit provides students with large observable effects while keeping cost to the minimum. Completed with an easy-to-use user interface and a set of carefully designed supplementary material including worksheets and lab technician guide, this toolkit aims to teach students the fundamental principles of ultrasound imaging via hands-on practice. They have designed it to be cheap, easy to set up, and portable. The effectiveness and impact of the toolkit were evaluated by ten undergraduate students who responded in the form of satisfaction questionnaires. To minimize the selection bias, we chose five students who had received no prior university-based instruction on ultrasound and five third-year biomedical engineering students who had learned about the topic previously. They demonstrated a strong interest in using the toolkit for a lab session and described it as user-friendly and highly engaging. [9]

2.5 Ultrasound pressure-controlled probe

Pressure-controlled ultrasound probe for reliable imaging in breast cancer diagnosis is the search address each of 'Yukina Matsumoto, Ayu Katsumura, MIKI Norihisa' in Japanese Journal of Applied Physics . Breast cancer is the most common cancer among women worldwide, with over 2 million new cases every year. Early detection can be achieved by screening examinations such as mammography and ultrasound imaging. Although the latter demonstrates advantages such as its safeness and its sensitivity to dense breasts, it is often performed as a follow-up test after an abnormal finding at mammography or palpable screening. Indeed, it is limited by operator-dependence and non-reproducibility since the quality of the imaging depends on the skill of the technologist performing the examination. Therefore, they designed a diagnosis assisting device composed of piezoresistive sensors of microscale thickness, that can be attached to the ultrasound transducer. The operator is informed when excessive pressure is detected, so that he or she can correct the position of the transducer. Finally, we fabricated a breast phantom including tumors from agar and collagen to assess the effectiveness of the device [10].

3.1 Methodology

Diagnostic ultrasound uses a small probe called a transducer. Ultrasound gel is placed directly on the part of the body that is to be examined and the transducer is then applied. High-frequency sound waves travel from the probe through the gel into the body. The transducer probe collects the sounds waves that bounce back to create an image which can then be viewed in real-time via a computer. Basically, the design and development of this project are divided into two main parts which are hardware architecture and software details. In the hardware architecture, the design of the circuit was constructed and the prototype of the project was built. While in the software development, the whole complete prototype was operated via programming codes.

3.2 Hardware

- ✓ Arduino Duo microcontroller.
- ✓ 5MHz 8mm Probe Transducer Sensor.
- ✓ TFT lcd shield 3.5.
- ✓ DC to DC step up converter.
- ✓ 9v 1A volt power supply adapter.

3.2.1 Arduino Duo microcontroller

The Arduino Due is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. It is the first Arduino board based on a 32-bit ARM core microcontroller. It has 54 digital input/output pins (of which 12 can be used as PWM outputs), 12 analog inputs, 4 UARTs (hardware serial ports), a 84 MHz clock, an USB OTG capable connection, 2 DAC (digital to analog), 2 TWI, a power jack, an SPI header, a JTAG header, a reset button and an erase button. [11]

The board contains everything needed to support the microcontroller; simply connect it to a computer with a micro-USB cable or power it with a AC-to-DC adapter or battery to get started. The Due is compatible with all Arduino shields that work at 3.3V and are compliant with the 1.0 Arduino pinout.

Technical specification:

Microcontroller	At91sam3x8e
Operating Voltage	3.3v
Input Voltage (Recommended)	7-12v
Input Voltage (Limits)	6-16v
Digital I/O Pins	54 (Of Which 12 Provide Pwm Output)
Analog Input Pins	12
Analog Output Pins	2 (Dac)
Total Dc Output Current On All I/O Lines	130 Ma
Dc Current For 3.3v Pin	800 Ma
Dc Current For 5v Pin	800 Ma
Flash Memory	512 Kb All Available For The User Applications
Sram	96 Kb (Two Banks: 64kb And 32kb)
Clock Speed	84 Mhz
Length	101.52 Mm
Width	53.3 Mm
Weight	36 G

3.2.2 5MHz 8mm Probe Transducer Sensor

Technical specification:

Name: Probe for Ultrasonic Thickness Gauge

Model: PT-08 (Lemo 00 connector)

Frequency: 5MHz

Diameter of the contact proportion: 8mm

Measuring Range: 0.8mm-300.0mm

Avaliable Contact Temperature: -10ºC-60ºC

Applicaiton: use for all Ultrasonic thickness gauge

3.2.3 TFT LCD shield 3.5 display

TFT Shields are touch-sensitive LCD screens for displaying images and creating user interfaces, with more or less complex graphics, to drive Arduino microcontrollers. In this tutorial, we use the Kuman TFT 3.5″ shield (very close to the 2.8″ shield) but this tutorial can be applied to other Shields or LCD modules. Check carefully the pins used and the compatibility of the library. [12]

3.2.4 DC to DC step up converter

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a flyback converter using a single inductor instead of a transformer.Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, ranging from much larger (in absolute magnitude) than the input voltage, down to almost zero.

The input voltage: 3-32 v

Continuous adjustable output voltage: 5v-45 v

Input current: 4 a (Max), no-load 18 ma

Module size: 44.7 (mm) x21.7 (mm)

Input mode: IN + input level is, the IN – negative input

4.1 Result and discussion:

After connecting the components together and trying each part of them, we did not get the expected results because some of the materials we did not get from inside the country and some of the replacement parts that were used do not meet the purpose. A hint from within the source that it may not work or work as intended. We did not get the expected results, but also we did not stop trying ways to operate as much as possible of the circuit, which is connecting the screen and programming the microcontroller to display the values on it and also connecting the sensor in a way that means giving a value and this value is greater than zero up to 80Hz or more and represented by a line that appears on the screen It represents the relationship between frequency and time. In the event that there is no object in front of the sensor, it will give a certain value, and if it is placed on the body, it will give a value of zero.

4.2 Conclusion

An ultrasound speaker doubles as a microphone. Brief bleeps are broadcast, and echoes are recorded from various depths. Graph of echo intensity versus time. The time for echoes to return is directly proportional to the distance of the reflector, yielding this information noninvasively. Sonography is a very important way in medicine to look inside the body. The principle is simple A transmitter sends ultra-sonic-pulses. They spread out in the body, are being reacted by inner organs or bones and come back to the receiver. The reacted pulses have to be stored and displayed by a microcontroller. The microcontroller must be in handly and easy to use as well as fast. Therefore, we choose an arduino due.

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