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Airborne Ultrasound Pulse Force Device for Palpation Simulation

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Abstract

This research is investigating the use of acoustic radiation pressure from ultrasound emitters to produce tactile feedback in medical simulators. An initial application would be to simulate a pulse palpation where the trainee doctor or nurse actively searches for a pulse with their fingers to locate an artery within the body. Our first steps towards achieving this aim are summarised below.

Category: L.2.II [Haptics]: Haptics Technology – Tactile Devices

1. Introduction

Whereas today there are many examples of force feedback devices being used in medical simulators, the use of tactile feedback is still in its infancy [CMJ11]. One recently demonstrated tactile interface is achieved by creating a pressure field from airborne ultrasound [ITS08]. We hypothesize that such an approach can be adapted to simulate the feel of certain human physiology, in particular the rhythmical throbbing of a pulse. To test this hypothesis we are building a palpation simulator whereby the trainee doctor or nurse actively searches for a pulse with their fingers to locate an artery.

First we shall review two very different devices that have been used in medical simulators. Then we briefly describe how ultrasound is configured to generate a pressure field. Finally we shall discuss our preliminary experiments for verifying our current hardware's capabilities and limitations i.e. the suitability of the components for building the ultrasonic device.

2. Existing Palpation Tactile Devices

A hydraulic mechanical system (Figure 1. Left) is used in a Femoral Palpation Simulator [CJG*11] to give tactile feedback for pulsation. A plastic tube filled with water runs

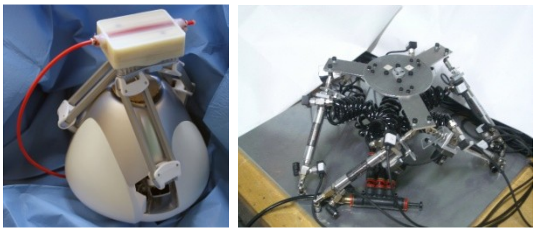

Figure 1: (Left) *Hydraulic Pulse. (Right) Pneumatic Parallel Manipulator*

underneath the surface of some silicone skin. The tube is connected to a motor that alters the water pressure. The change in pressure inflates and deflates the tube underneath the silicone surface to give a very realistic pulsation effect.

The hydraulic mechanism cannot control the region properties of the pulse i.e. the diameter and shape of the pulse's force. Another downside for this particular system is the maintenance required. The water inside the tube needs to be replenished frequently and is largely dependent on the environment the machine is situated in e.g. a warm room would degrade the system performance overtime far more quickly. If the tube is not completely water-filled then the pulsation effect is greatly reduced.

Six parallel pneumatic actuators (Figure 1. Right) are used in a Breast Cancer Palpation Simulator [TN07] to simulate different regions of stiffness on a silicone breast. There is a piece of wood sculpted to roughly follow the shape of the silicone breast's inner parts and is fixed to a platform whose position and contact area with the silicone breast can be configured by altering the displacement of six pneumatically actuated pistons. The displacement is configured accordingly to the feedback from pressure sensors that track the doctor's finger. The adaptability of such a device for representing different patient scenarios however is limited.

3. Ultrasound Tactile Feedback

The use of ultrasound to generate a focussed point of pressure in 3D space has been pioneered by Iwamoto et al [ITS08]. They successfully implemented a touchable hologram with simple 3D shapes.

Figure 2: *Angular array of ultrasonic transducers*

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Their device consists of an angular hexagon array of 40KHz transducers (Figure 2) to generate many ultrasonic waves. By exploiting the Acoustic Radiation Pressure phenomena and focussing the waves by controlling the phase of the signals, a method commonly used in radar systems, the ultrasonic waves are made to coincide at a particular point in 3D space where the peaks of one wave matches the peaks of another (Figure 3) to generate a higher pressure at that spot.

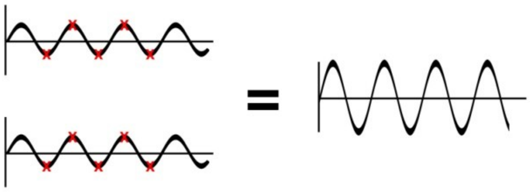

Figure 3: *Constructive interference. Peaks and troughs of one signal coincide with corresponding peaks and troughs of another signal to give a waveform with bigger amplitude.*

This is an attractive solution for immersive virtual environments where the need to wear special peripherals such as gloves is removed. This device is also expected to be much smaller compared to the devices previously mentioned. The current prototype however cannot give a force bigger than roughly 16mN and only has a single focal point. Physical measurements taken from patients at the Royal Liverpool Hospital show the palpation force to be in the range 39mN to 55mN. The challenge would be to develop the concept further to deliver a bigger force output.

3. Preliminary Experiment

An initial experiment was setup to test our current hardware for producing phase controlled signals. To generate a focal point of pressure, the correct phase has to be set in order for all the waves to coincide at that point. A focal point was arbitrarily chosen at 50mm above the plane of the aligned transducers. The phases between the signals were altered systematically to see the effects it has on the sound level at the chosen point (Figure 5).

Figure 4: *Experiment equipment and hardware*

An Arduino was used to generate several 1.8KHz square waves and was chosen because it provided a convenient USB interface between the PC and the physical circuitry. This feature would allow the medical simulator software to control the operation of the output device. These signals were then used to drive 1.8KHz audible transducers. An audible output allowed us to quickly verify whether the transducers were driven correctly. No amplification circuitry was needed as the audible transducers did not require high voltage levels. The output is also measurable by a readily available decibel meter.

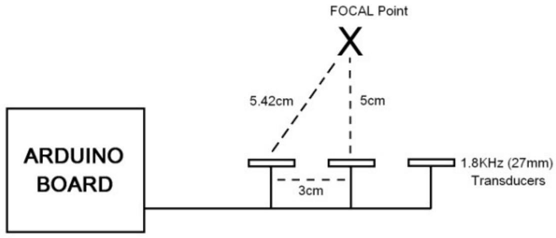

Figure 5: *Diagram of experiment*

4. Conclusion

Our findings show there is a relationship between the phase of the signals and the sound pressure level (Figure 6). At certain phases the sound level peaks. The effect is more prominent with additional transducers. Interestingly, when the signals are phased by 180º there is partial sound cancellation.

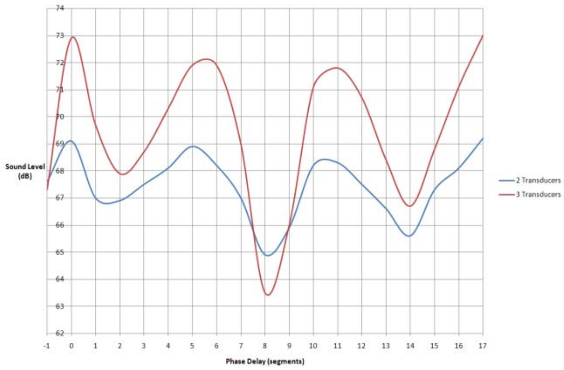

Figure 6: *Sound level at focal point as phase is cycled at 16 equal intervals*

The Arduino environment was limited in providing the performance required for 1.8 KHz audible signals. It was not possible to generate more than five different signals at a frequency of 1.8KHz. This is a major drawback as the ultrasonic device will require many driving signals and will also need to operate at 40KHz to emit ultrasonic waves.

The next step would be to look at microcontrollers for improved performance, driving a small array of 40KHz transducers with amplifying circuitry and take force output measurements.

5. References

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