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A study on Acoustic Tractor Beam Technology

Ms.Sudha T, Asst.Prof. Ms.Rini M K, Asst.Prof.Ms.Vincy DeviV.K
Department of Computer Applications Sree Narayana Gurukulam College of Engineering, Kadayiruppu, Kolenchery,Ernakulam,Kerala,India.

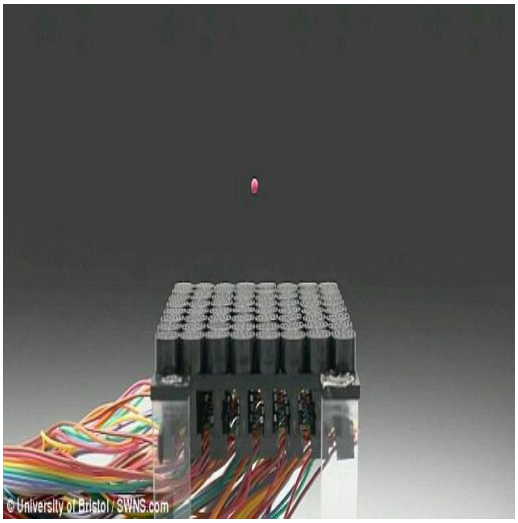
Abstract: *High frequency Sound waves can create oscillating packets of pressurized air, which can generate a force on particles capable of counteracting the pull of gravity. Many ultrasound levitation devices are developed based on this principle, which are working when two sound waves of the same frequency are emitted from opposite directions and superimposed on one another. That is, they require two sets of transducers to float the particles. Acoustic tractor beam is an emerging technology that can be applied to levitate and manipulate objects in air, water and human tissues with a single array of ultrasound emitters. It requires sound waves from one side to levitate particles. Acoustic tractor beam technology holds promise in a variety of fields. It can be applied for levitating and manipulating particles inside the body like kidney stones, clots, tumors and even capsules for targeted drug delivery. The technology also has some promising applications in outer space, where it can suspend larger objects in lower gravity and prevent them from drifting around uncontrolled.*
Keywords: *acoustic hologram, tractor beam, transducers, tweezers, trap*

I. Introduction

When we stand in front of a loud speaker we can perceive the force from sound waves. We can experience our bodies shake with the loud sound. The researchers have been conducting studies on these phenomena to make use of sound to put to good use by creating tractor beam using sound waves.

Researchers have been using many different things like superconducting magnetic fields and laser beams to levitate objects. Ultra Sound frequencies can levitate particles of a wide range of materials and sizes through air, water & biological tissues [1]. This permits us to move cells, compounds or living things without touching them. The principle behind this technology is high frequency sound waves can produce an acoustic force on objects capable of counteracting the pull of gravity [2]. Many ultrasound levitation devices are developed based on this principle in which the trapped particles had to be enclosed by acoustic elements. Acoustic levitation is well suited to the study of liquids including aqueous solutions, organics, soft materials, polymers, and pharmaceuticals at around room temperature [3].

Acoustic tractor beam is an emerging technology that makes use of 64 miniature loudspeakers as shown in fig (1), which is able to create high pitched and high intensity sound waves, generating an acoustic hologram that can lift, move, rotate and hold small objects. By controlling the output of speakers, the particles can be lifted, held stationary, moved & rotated.

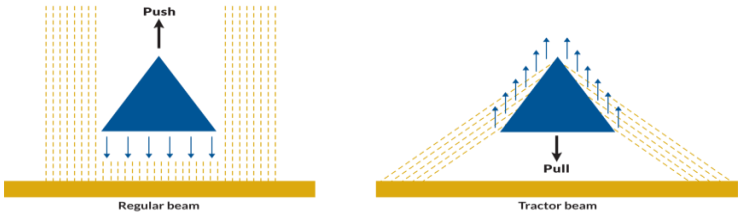


Fig(1)

The technique could be developed for a wide range of applications. Acoustic tractor beam can be applied in assembling subtle electronic components or taking drug capsules or very small surgical instruments through living tissue and cell. The devices that make use of this technology can move tissues, fluids and other things inside the body without any physical touch.

II. Tractor Beam

A tractor beam is a device which has the capability to pull towards one object to another from a distance. Since the 1990s, technology and research has labored to make it a reality, and have had some success on a microscopic level [4]. The technology permits users to levitate and move small particles without any physical contact. In the Fig (2) shown below, at left, waves marked as yellow dashed lines from a regular beam of light or sound tend to recoil an object shown as blue arrows and deliver a slight push. At right Waves from a new tractor beam is illustrated, that recoil the sides of an object and rebound upward. As a result, the particle gets pulled toward the source of the beam.



Fig(2)

A number of different ways of doing so have been proposed — including lasers and sound to levitate tiny particles in free space. Levitating objects using laser beam used a very powerful focalized laser which was able to trap the particles and move it towards the laser.

III. Laser Tractor Beam Technology

In Laser Tractor Beam technology, the objects are manipulated using light, i.e. pulling and pushing the objects over a much greater distance, up to almost 8 inches[5] as shown in Fig(3).

Fig (3)

Here, the light is projected through the air. This projected light will generate a hollow circle around the objects. As a result the light gets trapped and gets heated which in turn heats the particles, packed with kinetic energy. The trapped particles of air collide with the heated area of the sphere/object. The sphere which is used is in this technology is coated with gold. The collusion with the heated areas will bounce off and push the objects in the opposite direction. This technology has a laser tube which creates the complex patterns of excitation. These will give a rough estimate of the areas which heats fast. By varying these patterns of excitation the objects can be pushed forward or pulled backward. With this laser tractor beam objects can be moved up to 20 centimeters.

However, this technology failed in moving the objects beyond 20 centimeters and need to pump a lot of power into the laser. But the technology can't sustain for long period due to limitations of the equipment's used and the physical space.

Later, a new technology has developed to levitate the particles of different size in different media using ultrasound waves.The technology is called as acoustic tractor beam technology which uses the physical vibrations of sound to float objects without touching them. The device needs much less power and it's more powerful in terms of the materials that it can trap.

IV. How Acoustic Tractor Beam Works

The Acoustic Tractor Beam can levitate small objects and also manipulate them while they are in the midair. The high-frequency sound waves will helps them to accomplish this task. Even though the technology to levitate objects already exists it is the first device to employ a technique which relies on sound waves located only on one side of the manipulated object.

An array of 64 mini loudspeakers as shown in Fig (4), are arranged in a manner to generate high-pitched and high-intensity sound waves with microsecond level accuracy [6]. The sound waves will create an acoustic hologram that can lift, move, rotate and hold small objects in the air. Past acoustic levitation systems have used two or four arrays of these transducers and these transducers has to surround the system, but the researchers' models allowed them to create the same force field using just one array.

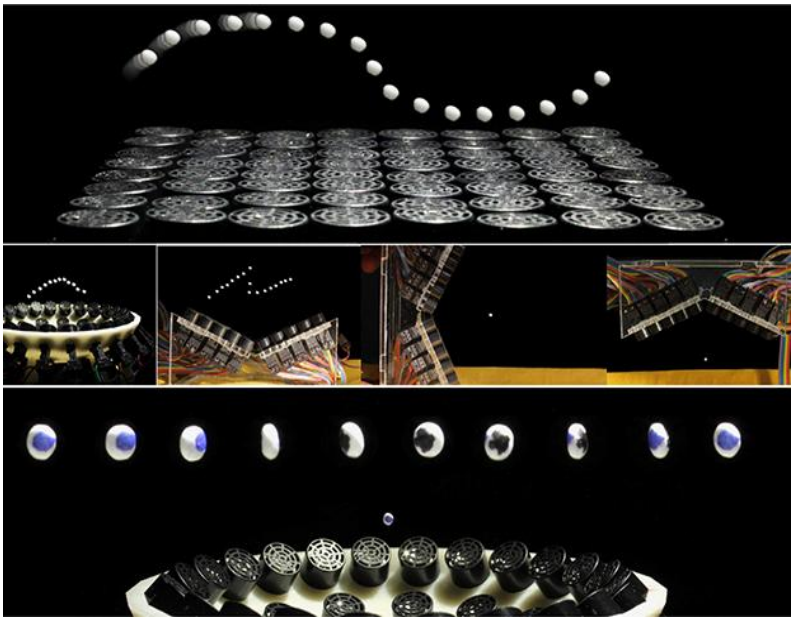


Fig (4)

The tractor beam surrounds the object which has a high-intensity sound and therefore creates a force field that keep the object in its place. By controlling the sound waves, the team could rotate, move or hold the object almost instantly. The acoustic hologram will take different forms such as tweezers, twisters and cages that exert forces on objects to levitate and manipulate them.

How it actually works is, the Acoustic transducers (10 mm diameter) that are driven at 16vpp and 40 KHz will generate acoustic waves which exert radiation forces. These acoustic waves are above the human hearing range but audible to dolphins and dogs. The forces generated by these waves in turn will converge at different points and generate acoustic traps which permit the levitation of particles of wide range of materials and sizes through air, water or biological waves. More clearly, Gor'kov potential defines a field, variations of which give the force. The Gor'kov Laplacian function at one position is used obtain the trapping strength at that point. The objects (small sphere) are dragged towards the region where the Gor'kov Laplacian is high. ie,by maximizing the Gor'kov Laplacian as a function of the phase modulation at a point, generates an optimum trap there. It generates three optimal traps that appear as optimum solutions for single sided arrays. They are:

1) Twin trap
2) Vortex trap
3) Bottle trap

1. **Twin Trap**

Twin traps are made to resemble the tweezers. Twin trap emerge when equal weights are specified in v-shape arrangements. These traps have two Finger – like cylindrical regions of high amplitude which tweezers the particle as shown in fig(5).

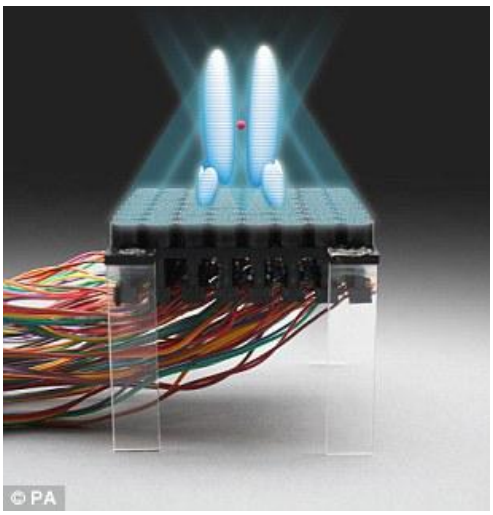


Fig (5)

2. **Vortex Trap**

Vortex traps emerge when equal weights are used in a hemispherical cap or flat array. This structure will trap the objects in the middle. A particle trapped in this vortex trap spins around its own axis.

3. **Bottle Traps**

Bottle traps emerge in all the arrangement when large weights are applied to the direction of propagation. This traps surrounds the object the object from all direction and keeps it in place. These traps create a high amplitude cage around the levitation point.

In fig (6), the acoustic tractor beam technology has been demonstrated using tiny balls of polystyrene, the same material used in packing peanuts.

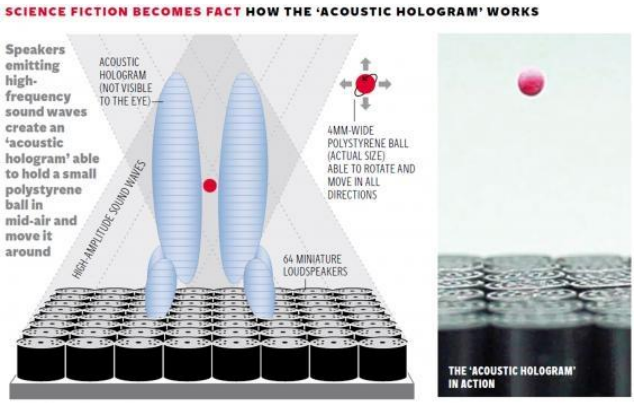


fig (6)

The device can levitate objects between 0.6 to 1/7th of an inch i.e. 4 mm in diameter. And the maximum size for the levitated objects is determined by the frequency of the sound waves –That is because the

object lifted needs to be smaller than the wavelength of the surrounding sound waves. If the frequency is lowered we can manipulate large objects but it would start to bring it into the audible range.

V. Applications

The applications of acoustic tractor beam technology are enormous in a variety of fields. Different holographic shapes can be created using this technique in order to manipulate an object, including tweezers, cages and fingers.

The most significant use of the technology is moving tiny things around and assembly of delicate objects without touching and disturbing them. There are many industrial applications where container less processing would be beneficial, for example, managing sensitive or dangerous materials such as pharmaceuticals or explosives.

The most immediate application is expected to be in medicine such as transporting drug capsules or micro-sized surgical instruments through living tissue and cell. Since the Sound waves can travel through water and human tissue, the most innovative application of this technology would in healthcare. These acoustic waves can control the particles inside the body. This is hence termed as *in vivo* manipulation, which means levitating and manipulating particles inside the body. And these particles could be kidney stones, clots, tumors and even capsules for targeted drug distribution. It's extremely interesting to think of using sound to manipulate within the human body without any surgery .The doctors could instantaneously image the action during *in vivo* manipulation since the ultrasonic levitation does not interfere with magnetic resonance imaging.

Cancer treatments can be improved with acoustic holograms**.** In cancer treatments like chemotherapy currently require flooding the body with the drug - if this could be more locally delivered it would be a major breakthrough. This is accomplished by delivering the drugs by neutralizing them into micro-capsule, which is blown open by high power ultrasound. So we could move and keep the micro-capsules in place (e.g., at a tumor) and periodically release it as required. We could use much smaller doses, which would result in fewer side effects.

VI. Conclusion

In this paper, we have discussed about how the sound waves can be utilized to levitate the small particles in the mid air. Currently, it is proved that particles up to 10mm diameter can float in the midair using ultrasound waves. The technology is expected to be work on much larger objects with the help of very high frequency sound waves. Hence, In future acoustic tractor beam can be applied in medical field to remove tumors, Cancer treatments, delivering drugs. The issue here is, the sound between 140 and 150 decibel is harmful to human beings and it should operate above 40 KHz.

This can create sound based assembly lines in electronic field, help to manipulate drugs in a patient's body and can create a sound controlled world. It is possible to create an area or region that effectively counteracts gravity. But it is difficult to create exact pattern of sound waves for tractor force. It is a great challenge to implement mathematical equations which are governing this behavior into a real world.

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