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A LOW-COST PASSIVE ACOUSTIC RESONATOR FOR INSECT-LIKE MICROROBOTIC SYSTEMS

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Abstract: This paper presents a novel implementation of a low-cost passive acoustic resonator for observing and amplifying inaudible sound produced by a microfork of an insect-like microrobot. The implementation demonstrates an alternative way of finding a simple yet practical, low cost, and effective solution for amplifying sound by fundamental of physics, instead of designing a complex electronic amplifier with much relatively higher cost. The implemented passive acoustic resonator has performed remarkably well, yielding sufficiently audible voice for the insect-like robots even for human.

Keywords: microrobot, microrobotic system, passive resonator, insect-like robot, acoustic resonator, low-cost resonator, sound amplifier.

1. INTRODUCTION

In recent years, intelligent behavior in animals have been attracted attention from researchers in robotics [1]. Emulation of insect behaviors by microrobots is one of research topics in the field of microrobotics [2,3]. As an infancy stage of this field, compared to the conventional robotics, many types of sensors and actuators need to be implemented to emulate functions of sensory and motor organs of insects such as vision, audition, muscular and nervous systems.

Implementation of vision and audition systems have been initially developed for such insect-like microrobotic systems. In some situation, audition systems have advantages over the vision ones such as no illumination requirement enabling a microrobot to work in darkness or low light, and no effects by obstacles enabling a microrobot to perceive audition information from sources behind obstacles.

Among application of audition systems to microrobots, it was reported by Aoyama [4] that a cricket-like-sound-genertor microrobot has been built sucessfully. The term "a cricket-like-sound-genertor microrobot" is definded as a microrobot that can produce sound imitating the method used by a cricket. A cricket produces sound by means of rapidly drawing a filelike structure on one fore wing over a thickened vein on the opposing wing [5]. However, the efficiency of the built-in sound generator of the cricket-like microrobots is very small and inadequate for communication among microrobots for collaboration in distributed autonomous tasks. The idea of implementation of the audition systems into the microrobots for distributed autonomous robotic systems, like insects collaborate to each other in a given task , is shown as in Figure 1.

To circumvent the low efficiency problem in producing sound as by the cricket-like sound generator, other types of sound generators need to be implemented. Upon observing the sound-generating organ of cicadas produced by means of vibrating membranes located on the underside of the male's abdomen, we found that the structure and method of sound generating of the cicadas'abdomen are similar to an acoustic resonator! From this point in this paper, as honor to the cicadas, we will call this type of resonator as the "cicada-type." For more information about cicadas, the reader is referred to reference [6]. Hence, an acoustic resonator can be applied as a passive acoustic amplifier for audition systems of insect-like microrobotic systems, which will be demonstrated about the implementation in the next sections.

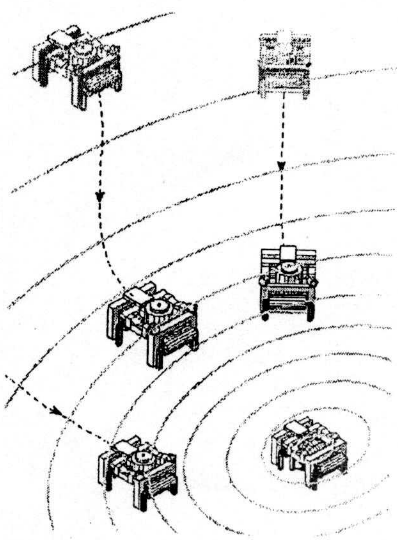

Figure 1: The communication by sound among microrobots.To circumvent the problem, other types of generators need to be implemented.

This paper is organized as follows: Section 2 provides fundamental concept of a passive acoustic resonator, known as the Helmholtz resonator; Section 3 demonstates the implementation of a spherical acoustic resonator as a low-cost sound amplifier for insect-like microrobotic systems; Section 4 presents experimental results, and Section 5 and 6 yield discussions and conclusions of the study, respectively.

2. FUNDAMENTAL CONCEPT OF PASSIVE ACOUSTIC RESONATORS

A simple example of a passive acoustic resonator is a bottle as shown in Figure 2. The neck at the entrance of the bottle is associated with an acoustic mass, M_a, the readiation of the neck corresponds to the radiation resistance, R_a, the body or cavity of bottle works as an acoustic capacitance, C_a, and the sound pressure, P_a, represents the input of the system. The mechanism of acoustic resonators is analogous to those of mechanical and electrical resonators. The equivalent mechanical and electrical circuits of the acoustic resonator can be illustrated as shown in Figure 3.

Not only the equivalent systems have the same form of circuits, but also they have the same form of equations and properties, yielding in transposing the properties, methods, behaviors, and so on, from one system to another [7]. The mechanically and electrically equivalent systems utilize mechanical and electrical engineers, for those who are not familiar in acoustic engineering, to think in their own disciplines. Analogously, as in the case of an electrical series-resonant circuit, the resonance frequency of the acoustic system is

$$f_0 = \frac{1}{2\pi\sqrt{M_a C_a}} \quad \text{Hz.} \qquad (1)$$

Since the shape of the acoustic resonator used in this paper is spherical as shown in Figure 4, we have

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{A}{V(t+0.85d)}} \quad \text{Hz.} \qquad (2)$$

, where c is the speed of sound, d is the diameter of the neck, A and t are the area and the thickness of the neck part, repectively, and V is the volume of the air cavity of the resonator (for convenience, we change the varible C_a to V). The readers are referred to reference [8] for more detail derivation of Eq. (2). We will employ Eq. (2) to design a low cost acoustic resonator in the next section. In practice, approximations are more often used.

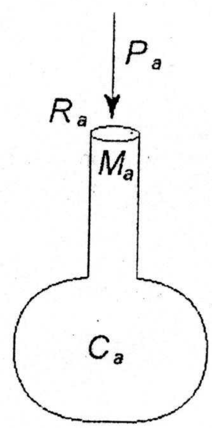

Figure 2: A simple acoustic system.

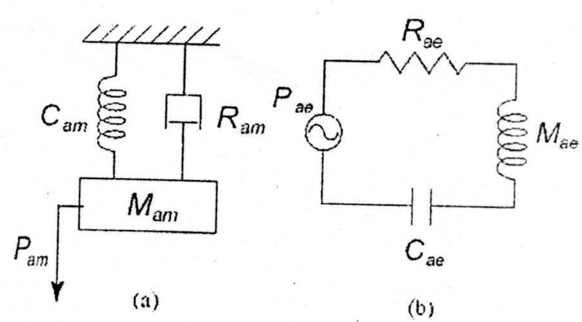

Figure 3: Equivalent circuits of the acoustic resonator: (a) a mechanical circuit, (b) an electrical circuit.

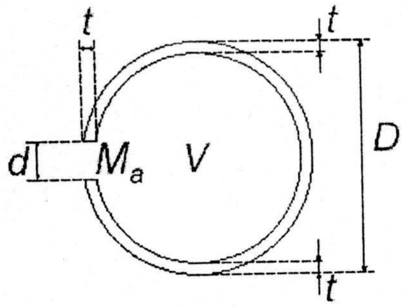

Figure 4: A spherical acoustic resonator.

3. A LOW-COST PASSIVE RESONATOR AS AN ACOUSTIC AMPLIFIER

In this section, we presents a low-cost passive resonator as an acoustic amplifier for insect-like microrobotic systems. The experimentation to validate the effectiveness of the implemented resonator is also conducted. The resonator used in this experiment is a X-mas decoration ball in spherical shape having the diameter of 25 mm with the diameter and thickness of of the neck equals to 3.6 mm and 0.1 mm, repectively. The weight of the ball is about 1.5 g, which is merely 3% of our microrobot. The diameter of the neck was calculated approximately by using Eq. (2) combined with the experiences obtaining from reference [9] at the expected resonance frequency around 1000 Hz, with the sound velocity of 346.79 m/s. The velocity of the sound was calculated by using the method in reference [10], at the temperature 25 °C and humidity at 30%RH measured at the time the experiment was conducted. Figure 5 shows the closed-up picture of the microfork and the resonator.

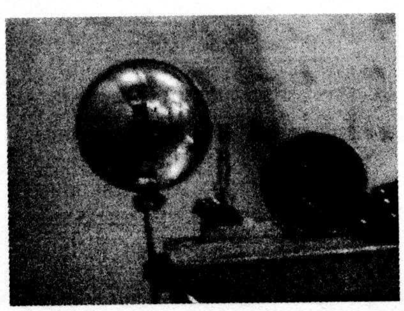

Figure 5: Photograph of the microfork and the resonator used to immitated the cicada's sound producing organ.

Based upon the experiences in the past [9], which the authors performed the experiments on various sizes of the ball, the hole, and the thickness of the resonator, we found that the optimal size of those parameters for our microrobots must have dimension and specification as mentioned in the above.

Another reason that the diameter of the resonator cannot exceed the limit of 25 mm is that our microrobots have dimension of 30x30 mm on the x-y plane. We will later on integrate the resonator, microfork, and microphone into the micro robots, which is not in the scope of this paper. In addition, the optimal acoustical position of the microfork manufactured by Murata manufacturing Co., Ltd., located away from the hole of the resonator is about 0.01 mm [9]. The set-up system diagram for the experiment is shown in Figure 6.

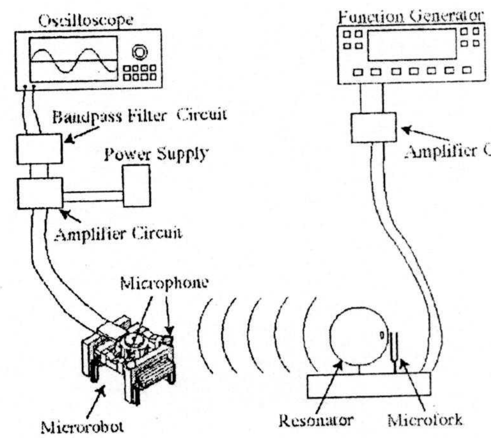

Figure 6: The experiment set-up diagram.

In this experiment, the function generator used to generate sound wave is the TOA Abitary Waveform Synthesizer FS-2221. The setting parameters for the waveform synthesizer are as follows.

Type of wave form:	Sine Wave
Amplitude:	72 mVpp
Phase:	0.2 degree
Offset:	0.000 V
Attenuation:	40 dB
Maximum amplify:	10 Vpp.

4. EXPERIMENTAL RESULTS

In this experiment, we placed the microrobot equipped with two microphones in the opposite side of the resonator's hole. The reason is that the sound signal generating by the resonator from the front is stronger than from the back side. If the microrobot can receive the signal effectively from the back side of the resonator, needless to test from the front. The experiment was performed in the sound-lab of the AOLAB located on 3rd floor of the Satellite Venture Business Laboratories at the University of Electro-Communication, Tokyo, Japan..

The collected data from the experiment shown in Figure 6 is presented in Figure 7. The receiving signals at the microphone of the microrobot are measured and read directly from the oscilloscope. The signals from the microfork with the resonator or without it are also compared. According to Figure 6, the 3 mV constant signals receiving shown in the case of absence of the resonator is a noise signal generated by the sound wave synthesizer as we carefully measured.

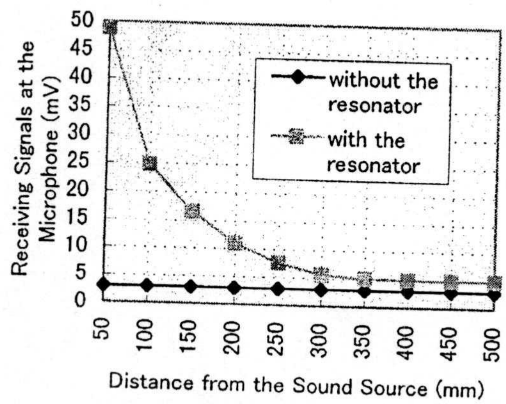

Figure 7. Receiving signals at the microphone of the microrobot in various distances away from the resonator.

The sound signal generating by the microfork without the resonator is almost negligible when hearing by the microphone of the microrobot or with human ears. With the resonator, the sound is amplified and sufficiently audible even by the human ears! The distance for human hearing the sound generating by the cicada-type resonator in this experiment is up to 1 meter.

5. DISCUSSION

The curve of the receiving signals at the microfork shown in Figure 6 confirms the inverse square law of the power of sound versus distances. It is also easy to see from the figure that even the relatively far distance for the microrobot operating within the working area on a desk-top, say 500 mm, the amplified sound by the cicada-type resonator is still better than the absence of the resonator counterpart.

The working areas on the desk-top for microrobots at AOLAB has dimension of 500x500 mm. The planing distributed-autonomous-robotic scheme, imitating collaboration of insects for a given task, has a central microrobot worked as a coordinator stands at the middle of the working area. Each microrobot as an agent or a worker is located apart from each other around 100-150 mm atmost. This implies that each microrobot can hear each other, as can be seen from Figure 7 that the receiving signals is around 17 mV. In addition, in the relatively worst case that a microrobot travelling out of the operation range, say 200 mm away from the coordinator at the center of working space and no other microrobots nearby, that microrobot is still capable to hear the calling signal from the coordinator, whereas the microrobot without the resonator counterpart is completely inaudible for all cases.

As far as the practical view-points are concerned, our cicada-type resonator has proved to provide a relatively rich amplification of sound signals. Needless to say about cost of the implementation of the resonator versus the performance, the cost of implementation is absolutely as low as a X-mas decoration ball. Besides the cost-effectiveness advantage, the advantage of realizing a passive resonator over an electronically active one is that the cicada-type resonator do not need any wiring or need more sophisticated electronic components. This means that we need not worry about the fabrication. Moreover, the wiring and more electronic components could effect the behaviors of the microrobots in terms of electrical noises and inertia.

In this experiment as a validation and demonstration of the effectiveness of the cicada-type resonator, we measured the audio signals receiving at the microphone of the microrobot by placing the microphone at the backside of the resonator's hole in various distances. The experiment reports a satisfactory result with a guaranty for cost effectiveness. This means that, if the microphone is in the direction facing to the resonator's hole, the microrobot is definitely capable to hear the stronger signal, compared to the backside position. Hence, based upon the cost per performance, the implementation of the cicada-type resonator as demonstrated in this paper has proved to be a good altenative among audition amplifier candidates, by which can amplify sound signal sufficiently, effectively, and economically.

6. CONCLUSION

In this paper, a low-cost passive acoustic resonator for insect-like microrobotic systems has been presented. By imitating the method used for producing sound of cicadas, a helmholtz resonator can be realized as a passive sound amplifier. To demonstate the effectiveness of the implementation, a X-mas decoration ball is used as a passive resonator. The experimental results show a satisfactory performance with very low-cost investment to realize a sound amplifier for insect-like robotic systems. This paper also demonstrates a way to search for simple solutions by employing fundamental of physics instead of generating more complex expensive electronic solutions.

The next step of having the cicada-type resonator is to integrate it into a part of audition systems for microrobots. This is a step to establish communication by sound between insect-like microrobots of the authors. The ultimate goal is to achieve a successful distributed autonomous microrobotic systems.

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