Development of Vocal Cords of an Infant-like Vocal Robot based on Anatomical Structure*

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***Abstract*— Several observational studies suggest that the interactions of infants with their caregivers may have an important role in infant vocalization for language acquisition. However, what underlying mechanism works and how it is influenced by the caregiver's behavior are still not clear. We have built an infant-like vocal robot "Lingua" as a controllable vocal platform. However, the vocal cords could not reproduce the infant's crying that exceeds 1000 Hz. We redesigned the structure of the vocal fold and employed two-layered structure based on its anatomical structure. The experimental results showed that new vocal cords could reproduce a high pitch over 2000 Hz.**

I. Introduction

Speech is one of the important means of human communication, and the experimental observations by developmental psychologists have suggested that the non-verbal and emotive utterances of infants to caregivers influence their speech development [1]. However, the underlying mechanisms of the process and how they are affected by the behavior of the caregivers are yet to be fully understood. To address this problem, we have developed an infant-like vocal robot *Lingua* [2], aimed at building a controllable platform robot with infant-likeness and high articulation abilities, which human infants possess.

However, Lingua could vocalize only the fundamental frequency of a human infant's babbling (250- 500 Hz) while a human infant exceeds 1000 Hz in crying. Therefore, we decided to improve the Lingua's sound source, the vocal cords.

II. Vocalization

Human's vocal organs consist of lungs, vocal cords, and vocal tract. Vocal cords play the role of a sound source generator and consist of two folds. The folds have a multi-layered structure that can be generally divided into two: a hard inner layer with the arytenoid muscle and vocal ligament, and a soft outer layer with the mucous membranes [3].

During vocalization, the outer mucous membrane moves from the bottom to the top like a wave. The inner muscle and ligament move very little. This type of vibration with a phase difference between the top and the bottom is called a "mucous membrane wave", and this allows stable vocalization and high pitch vocalization. We should carefully choose the parameters of Lingua's new vocal cords because at a high pitch, the cords are harder and extended, which causes a decrease in the phase difference and the cords are unable to produce voice eventually [4].

III. New Artificial Vocal Cords

Lingua's old vocal cords comprised uniform silicone resin (Dragon Skin FX-Pro, Smooth-On Inc.), and the fold was a single-layered structure. To reproduce the mucous membrane wave for high pitch vocalization, we designed two-layered vocal cords (Fig.1). In this process, each layer is molded in a different hardness of silicone: a soft (more plasticizer) outer layer and a hard inner layer.

To measure the acoustic performance of the new two-layered vocal cords, we designed 49 vocal cords with different parameters concerning the thickness and hardness of the two layers. Then, we examined their performances by setting them to Lingua and deforming them manually. Eventually, one of them could vocalize in the widest range of pitch 405- 2047 Hz. In this experiment, by changing the parameters, we confirmed that the adequate thickness and softness of the outer layer and the hardness of the inner layer are essential for high pitch vocalization.

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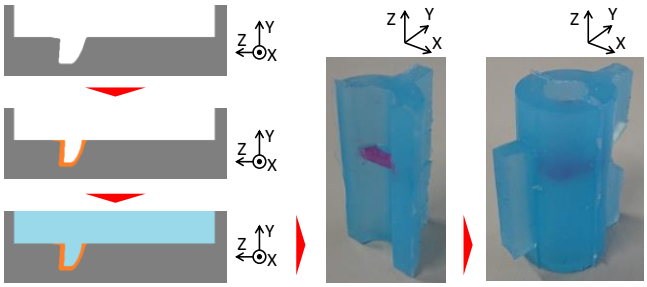

Figure 1. Fabrication process of the two-layered vocal cords.

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