Design of an Articulation Mechanism for an Infant-like Vocal Robot "Lingua"

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1 Introduction

Spoken language is one of the important means for humans to communicate with others. In developmental psychology, it is suggested that an infant develops it through verbal interaction with caregivers by observation experiments [1]. However, what kind of underlying mechanism works for that and how caregiver's behavior affects on this process has not been fully investigated yet since it is very difficult to control the infant vocalization. On the other hand, there are several constructive approaches to understand the mechanisms by using infant robots with abilities equivalent to those of human infants, as a controllable platform [2].

Sasamoto *et al.* suggest a vocal robot as a platform for constructive investigation of the developmental process of vocalization [3]. Unlike speech conversion and articulation simulators or speech synthesis, robotic platforms have advantages in terms of realtimeness, consonant vocalization by means of flow-acoustics, and interaction with humans. They actually built an infant-like vocal robot that mimics the anatomical shape of the articulator of human infant, and showed that its vocal cords and vocal tract could vocalize vowels in the same range of formant frequencies as that of human infant. However, the driving mechanism could not vocalize the same range because it did not comprise enough degrees of freedom (4-DOFs for tongue, 1-DOF for jaw, 1-DOF for soft palate).

On the other hand, vocal robots which have many degrees of freedom for articulation and can vocalize as well as human adults have been developed [4, 5]. Particularly, Fukui *et al.* [4] developed the vocalization robot WT-7RII which could vocalize not only vowels but also consonants by controlling many degrees-of-freedom (7-DOFs for tongue, 1-DOF for jaw, 1-DOF for soft palate, 5-DOFs for lip). However, this robot focused on reproduction of adults' utterance instead of infants'. Between adults and infants, the size of the articulator is different, which is closely related to the difference in their vocalization. The shapes of vocal cord [6] and vocal tract [7] change with the growth. It is necessary to consider the changes in order to understand infant's vocal development [8]. Therefore, in order to reproduce infants' vocalization by means of many degrees of freedom (like WT-7RII), the problem of miniaturization has to be solved.

In this study, aiming at reproducing the infant vocalization, we miniaturized the articulation mechanism of WT-7RII, and developed a new infant-like

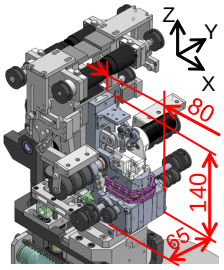
vocal robot named "Lingua". This paper describes the design of its articulation mechanism.

2 Design of the Articulation Mechanism and Preliminary Evaluation

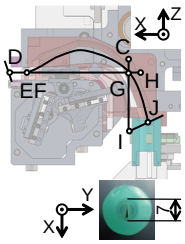
Fig. 1 shows a Lingua's overview, DOF configuration, and structural properties of the vocal cords and tract. This robot consists of a lung, vocal cords, and a vocal tract. The lung and the driving mechanism of the vocal cords are those of WT-7RII. We used the same vocal cords made from soft material as for the infant-like vocal robot by Sasamoto *et al.* [3]. The shape of Lingua's vocal tract is based on the anatomical data of 6-month-old infants [6, 7].

The tongue mechanism consists of 7-DOFs that combine rotational and linear movement (Fig. 2). We downsized the linkage mechanism which connects them. The linkage of WT-7RII's tongue consisted of plural shafts by parallel and slider cranks, but we minimized the parallel crank by adopting a coaxial mechanism for it. The movable range of each linkage tip was determined based on simulation results of infants' 3 vowels utterances (/a/, /i/, /u/) by a VLAM (Variable Linear Articulatory Model) articulation simulation [9]. The layout and dimensions of the linkage were determined based on the range calculated by inverse kinematics. The surface of the tongue was molded in silicone rubber. We calculated the elastic coefficient of the tongue based on measuring its stretching when exposed to external load. Then, we designed the mechanical parts such that the minimum yield safety ratio could be 5 by using FEM. Hence, the linkages have enough strength against reciprocating articulatory movements.

We measured formant frequencies of Lingua's vowel vocalization (graph in Fig. 2). This means that Lingua has ability to vocalize the vowels as well as human infant.



Part	DOF
Upper jaw	1
Lower jaw	8
Vocal cords	2
Lungs	1
Total	**12**



Parameter	Length [mm]
VTL (D to J)	93
VT-V (I-C)	39
PCL (I-G)	27
NPhL (G-C)	12
VT-H (D to H)	65
LTh (D-F)	10
ACL (F to G)	45
OphW (G-H)	10
VT-O (F-H)	55

Fig. 1. Lingua's overview, DOF configuration, and structural properties of the vocal cords and tract

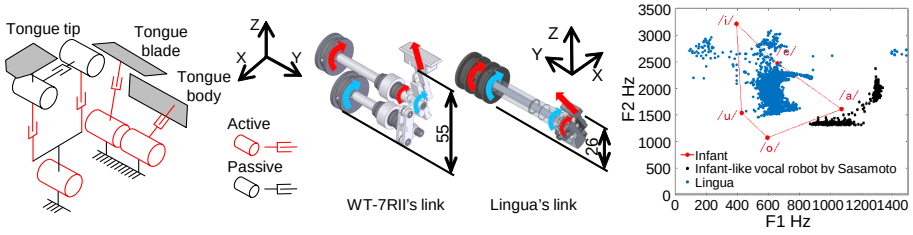


Fig. 2. DOF configuration of Lingua's tongue and comparison of the link mechanisms between WT-7RII and Lingua

3 Conclusion and Future Works

In this paper, we described the design of the articulation mechanism of the infant-like vocal robot "Lingua". Preliminary evaluation shows Lingua's ability to vocalize the vowels as well as human infant. In the future, we will develop the lip mechanism and examine the vocalization performance of the overall mechanism for vowels and consonants. We also aim to reproduce crying and babbling. Moreover, we will conduct interaction experiments between the robot and a caregiver in order to investigate how infants' vocalization develops.

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