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Development of an anthropomorphic musical performance robot capable of playing the flute and saxophone: Embedding pressure sensors into the artificial lips as well as the re-designing of the artificial lips and lung mechanisms

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HIGHLIGHTS

- The development of the Waseda Flutist Robot No. 4 Refined V is described.
- Authors aim to enable the flutist robot to play the flute as well as the saxophone.
- The artificial lips were re-designed for embedding pressure sensors.
- The lung mechanism was re-designed to output about 4 kPa for playing the saxophone.
- In order to automate the calibration control for 1-DOF, an algorithm has proposed.

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ABSTRACT

The authors are developing anthropomorphic musical performance robots as an approach to understand the human motor control and to enhance the human–robot interaction from an engineering point of view. For this purpose; since 1990, we have developed an anthropomorphic flutist robot. As one of our long-term approaches, we aim to develop an anthropomorphic musical performance robot capable of playing different kinds of woodwind instruments, e.g. flute and saxophone. In this paper, the improvements of the mechanical design and sensing system of the Waseda Flutist Robot No. 4 Refined V (WF-4RV) are detailed. As for the sensing system, an array of sensors has been designed to detect the lip's pressure distribution. On the other hand, the lips and lung have been re-designed to enable the flutist robot to play the saxophone.

1. Introduction

The development of wind instrument playing anthropomorphic robots has interested researchers since the golden era of automata. As an example, we may find some classic examples of automata displaying human-like motor dexterity to play instruments such as the "Flute Player" [1]. The design principle for the "Flute Player" was that every single mechanism corresponded to every muscle [1]. Thus, Vaucanson arrived at those sounds by mimicking the very means by which a man would make them. Nine bellows were attached to three separate pipes that led into the chest of the figure. Each set of three bellows was attached to a different weight to give out varying degrees of air, and then all pipes joined into a single one, equivalent to a trachea, continuing up through the throat, and widening to form the cavity of the mouth. The lips, which bore upon the hole of the flute, could open and close; and move backwards or forwards. Inside the mouth was a moveable metal tongue, which governed the air-flow and created pauses [1].

More recently, the "Flute laying Machine" developed by Martin Riches was designed to play a specially-made flute somewhat in the manner of a pianola, except that all the working parts are

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clearly visible [2]. The "Flute Playing Machine" is composed of an alto flute, blower (lungs), electro-magnets (fingers) and electronics. The design principle is basically transparent in a double sense. The visual scores can be easily followed so that the visual and acoustic information is synchronised.

Furthermore, Toyota Co. has developed the trumpet-playing robot capable of playing the trumpet while it was walking [3]. The trumpet player stands about 1.5 m tall and weighs 46 kg. Complete with artificial lungs and lips, the two-arm/handed musician plays a real trumpet and fingers the valves as would a human [3].

On the other hand, one of the first attempts to develop a saxophone-playing robot was by Takashima at Hosei University [4]. This robot, named APR-SX2, is composed of three main components: a mouth mechanism, the air supply mechanism, and fingers. The artificial mouth consisted of flexible artificial lips and a reed pressing mechanism. The artificial lips were made of a rubber balloon filled with silicon oil with the proper viscosity. The air supplying system consists of an air pump and a diffuser tank with a pressure control system. The APR-SX2 was designed under the principle that the instrument played by the robot should not be changed. A finger mechanism was designed to play the saxophone's keys, and a modified mouth mechanism was designed to attach it to the mouthpiece, and no tonguing mechanism was implemented. The control system implemented for the APR-SX2 is composed of one computer dedicated to the control of the key-fingering, air pressure and flow, pitch of the tones, tonguing, and pitch bending [4]. In order to synchronise all the performances, the musical data were sent to the control computer through a Musical Instrument Digital Interface (MIDI) in real-time.

The authors have developed the Waseda Flutist Robot No. 4 Refined IV (WF-4RIV) [5]. The WF-4RIV has a total of 41-DOFs, which mechanically simulate the human organs involved during the playing of the flute. The WF-4RIV mechanically reproduced the anatomy and physiology of the following organs: lips (3-DOFs), neck (4-DOFs), lungs and valve mechanism (2-DOFs and 1-DOF, respectively), fingers (12-DOFs), throat (1-DOF), tonguing (1-DOF), two arms (each with 7-DOFs) and eyes (3-DOFs). The WF-4RIV has a height of 1.7 m and a weight of 150 kg. In addition, in [6], the authors proposed as a long-term goal enabling the flutist robot to interact more naturally with musical partners in the context of a Jazz band by implementing a Musical-Based Interaction System (MbIS).

Moreover, the authors introduced in [7], the Waseda Saxophonist Robot No. 2 Refined III (WAS-2RIII). The WAS-2RIII has improved the air compressor design for reducing the effect of the ripple to improve the sound quality. Furthermore, an eye mechanism was designed to enable the saxophonist robot to acquire visual information from the musical partner. In particular, the WAS-2RIII is composed of 27-DOFs that reproduce the physiology and anatomy of the organs involved during the playing of the saxophone as follows: 2-DOFs to control the shape of the artificial lips, 1-DOF for the control of the shape of the oral cavity, 1-DOF for the tongue control, 19-DOFs for the human-like hand, 2-DOFs for the lung system and 2-DOFs for the eye mechanism.

From the above researches, the development of a single musical performance robot capable of playing different wind instruments has been scarcely studied. In fact, human musicians capable of playing a wind instrument (either flutes or reed instruments) can interact with other musicians performing with other kinds of wind instruments. However, it is not clear how they are able to musically interact and even imitate some musical styles even while playing different wind instruments. Therefore, it would be important to study in more detail the human–robot interaction (HRI) in a musical context.

Thus, the main goals of our research are to facilitate the understanding of human motor control (Robotic Human Science), to facilitate the understanding of human–robot interaction (symbiosis) as well as to introduce novel ways of expression (entertainment). As for the entertainment point of view, in [6], the authors have presented and evaluate the performance of a Musical-based Interaction system implemented in the WF-4RIV. However, it has been scarcely studied the entertainment effect when a musical performance robot playing with different wind instruments and musical styles and their effect in the audience. As a first step, the authors proposed to develop an anthropomorphic musical performance robot capable of playing different kinds of wind instruments.

Due to the complexity of such a long-term goal; as a first approach in this paper, the authors have focused to enable the anthropomorphic flutist robot to play a typical example of a reed instrument, e.g. the saxophone. For this purpose, it is required to re-design different mechanism systems: lungs, lips, hands and arms. In particular, the authors have focused at first to re-design the artificial lips and lung mechanisms for enabling the flutist robot to play the saxophone. In addition, an array of sensors were embedded into the artificial lips in order to analyse the distribution of lip's pressure while playing different notes. In Section 2, an overview of the sound production principle for the flute and the saxophone is given. In Section 3, an overview of the re-design of the mechanism design as well as the embedding of the array of sensors for the WF-4RV is described. Finally, in Section 4, a set of experiments is presented in order to verify the feasibility to measure the distribution of the lip's pressure by the proposed sensor array, as well as to verify the improvements achieved with the proposed mechanical re-design to play the saxophone.

2. Sound production principle

The sound of wind instruments is a self-excited oscillation [8]. The sound production system comprises three major elements: energy source, generator, and sound resonator. The sound generator includes the dynamics of reed vibration and air flowing through a reed aperture for reed woodwind instruments (e.g. the Saxophone) and the dynamics of vibration of air at the hole embouchure for reedless woodwind instruments (e.g. the Flute). The sound resonator is related to the air column resonance of the instruments. In a single reed woodwind instrument, a flow modulated by the reed in the generator enters the resonator and excites an oscillation of the air column. As a response, the resonator generates sound pressure at the entrance to the acoustic tube and it acts as an external force on the reed and influences the vibration frequency of the reed. In this manner, the sound production system forms a feedback loop (refer to [9] for a schematic diagram). If the loop gain becomes positive and overcomes losses such as the acoustic radiation, the system yields a self-excited oscillation or sounding. In order to develop musical performance humanoid robots, we are required to understand in detail the principle of sound production of the instrument as well as the mechanism of humans to control different kinds of properties of the sound. In particular, in this section, we will provide a general overview of the differences in the principles of sound production between the flute and the saxophone.

The flute is a reedless woodwind instrument which is driven by an air beam characterised by its length, thickness, angle and velocity [10]. Slight changes of any of these parameters are reflected in the pitch, volume, and tone of the flute sound (Fig. 1(a)). Thus, the flutist robot requires to perform a calibration procedure in order to search the "General Position", which is based on the relative distance between the robot's mouth and the flute mouth piece [11]. Using the "General Position", the flute robot can blow a all the notes with a uniform sound quality. However, in order to automate the searching of such position, at first, an array of sensor are require to collect data.

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