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ON THE CAPABILITIES OF A 'DIGITAL MOUTHPIECE' FOR REAL-TIME RECORDING OF EMBOUCHURE PARAMETERS FOR BRASS MUSICIANS

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ABSTRACT

The real-time acquisition of relevant acoustic parameters in brass instruments' embouchure usually requires expensive measurement setups. This paper describes the operating principle as well as the preliminary design of a digital and connected mouthpiece, which makes it possible to 1. perform, 2. wirelessly transfer to a mobile device, and 3. process and display these measurements, in an easy way and at low cost. The digital mouthpiece is based on a standard mouthpiece equipped with several microelectronic components and sensors. It enables the measurement, while playing, of the separate forces exerted by the upper and lower lips on the mouthpiece and of the upstream and downstream pressure. The system also includes a microphone to identify and analyse the possible correlations between the applied forces, the measured pressures, the sound frequency, and the sound pressure level. In this paper, we also present the first experimental results obtained with the digital mouthpiece, in the frame of test runs conducted with musicians from the Gustav Mahler University in Austria.

Keywords: *Digital mouthpiece, embouchure parameters, 3D-print*

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1. INTRODUCTION

Brass musicians' embouchure data are of interest from a scientific as well as from a pedagogical perspective. In the last years, efforts to develop increasingly accurate, complex and expensive measurement techniques for research into sound production by brass musicians have notably led to new insights in this field [1–3]. However, the measurement setups that are currently used to acquire experimental data can most often only be used to collect data from a limited number of musicians, as they are constrained to one location (e.g., a laboratory) or made available for a limited period of time only. Real-time access to such data is also usually not possible for performing musicians. This is unfortunate, as such data could be advantageously used by the musicians to objectively analyse their own performances and achieve faster progress (e.g., by correcting embouchure-related issues, as described by Woldendorp et al. [4]).

Luckily, the increasing interconnection of physical objects in a digital world (Internet of Things) [5] accompanied by the steady introduction of ever smaller, cheaper and more efficient sensors and microcontrollers, enables new developments and continuous improvement in the field of brass musicians' performance monitoring. These range from "augmenting" the capabilities of musical instruments and facilitating the process of music creation, to the development of low-threshold data acquisition tools, as mentioned by Campbell et al. [6]. In 2015, Grosshauser et al. notably demonstrated that "mouthpiece force" can easily be measured using low-cost sensors, which later resulted in the QuantiForce Brass learning aid [7, 8].

The complementary use of low-threshold, less accurate, to high-precision measuring devices results in much more experimental data being generated. This makes it possible to better understand brass musicians' individual ways of sound production. In addition, this valuable data becomes both real-time and widely available, allowing musicians to use it to improve their performance more effectively.

2. DIGITAL MOUTHPIECE - CAPABILITIES

The basic idea behind the digital mouthpiece is to position sensors as close as possible to the lips of brass musicians, as this is where both the coupling to the instrument and the conversion from a relatively constant air pressure (in the mouth cavity) to an acoustic pressure take place.

performed via a thin plastic tube, which can be replaced after use. The measurement of air pressure inside the mouthpiece is performed via an air channel, directly integrated (by design) into the cup. Furthermore, three load cells (Honeywell FMAMSDXX025WCSC3, measuring range: up to +25N, [12]) are used to measure the axial force exerted on the mouthpiece at three points around the mouthpiece rim, while playing. The load cells are arranged evenly at 120° around the axis of symmetry so that the forces exerted by the upper and lower lips can be approximately distinguished by a calculated equilibrium of forces (see Figure 2 and Equations 3 and 4).

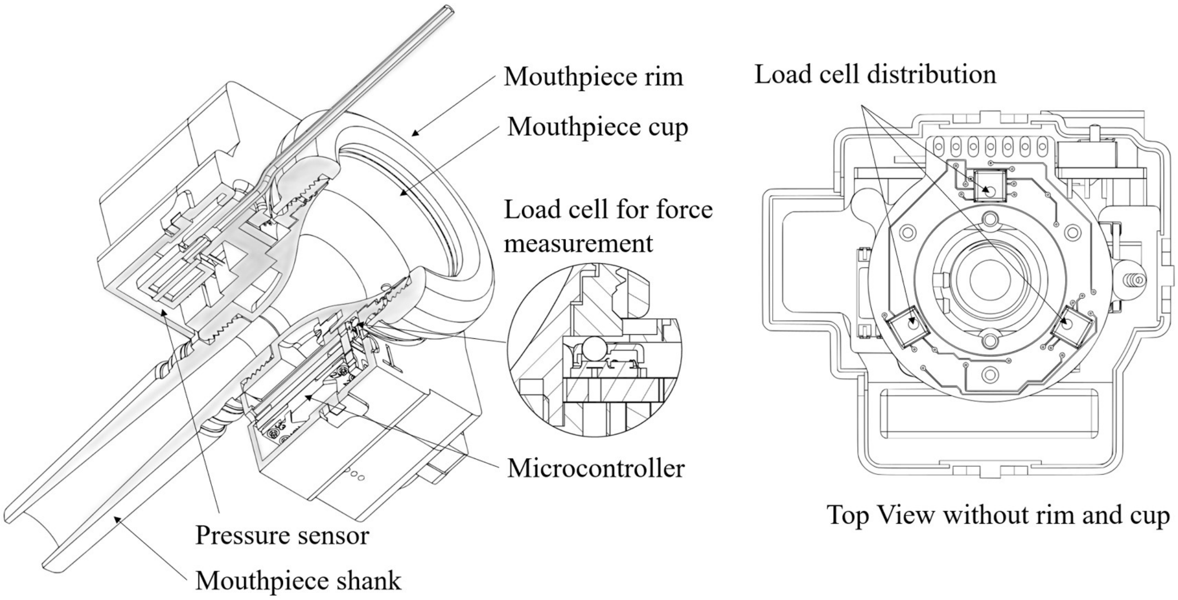

Figure 1. Structure of the digital mouthpiece for trombone

The sensors are integrated into the 3D-printed cup of a three-part mouthpiece, allowing musicians to adapt the measuring system to individual needs by using different shanks and rims (see Figure 1). A microcontroller (e.g. ESP32 TinyS3 [9]), an RF module and a battery are also integrated in the mouthpiece, which makes it possible to use the device wirelessly [10]. Biocompatible PA12 polymer (according to the EN ISO 10993-1 norm) is utilised in the selective laser sintering process to produce the basic parts of the digital mouthpiece.

Two AMSYS bi-directional pre-amplified pressure sensors (AMS 6915 and AMS5915 [11]) are used to measure the air pressure in the oral cavity and in the mouthpiece cup. The measurement of air pressure inside the oral cavity is

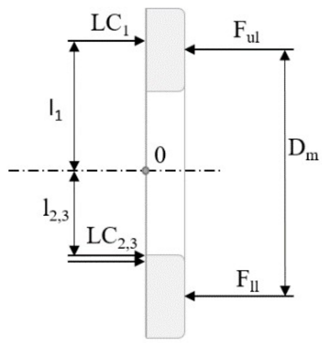

Figure 2. Schematic cross-section illustration of the force measurement (LC_1=Load cell 1, $LC_{2,3}$=Load cell 2&3, F_{ul}=Force of the upper lip, F_{ll}=Force of the lower lip, D_m=Diameter of the mouthpiece rim, l_1=distance of load cell 1, $l_{2,3}$=distance of load cell 2 and 3) [10]

$$\sum \vec{F} = 0 \tag{1}$$

$$\sum M_0 = 0 \tag{2}$$

$$F_{ll}=\frac{1}{2}(LC_1+LC_2+LC_3)-D_m^{-1}\left(LC_1 l_1-(LC_2+LC_3)l_{2,3}\right) \tag{3}$$

$$F_{ul}=\frac{1}{2}\left(LC_1+LC_2+LC_3+\frac{2}{D_m}\left(LC_1 l_1-(LC_2+LC_3)l_{2,3}\right)\right) \tag{4}$$

A low-cost ICS-43434 MEMS microphone is used to link the acquired data to the sound pressure level and sound frequency spectrum. The platform was designed so that new sensors can be easily added.

Accurate measurement of mouthpiece forces requires that the rim of the mouthpiece presses directly on the load cells. For this purpose, the mouthpiece cup is divided into two parts: a movable part to which the mouthpiece rim is attached and a fixed part to which the load cells are attached. Air-tightness between these two parts is achieved using customised silicone gaskets.

The system can be calibrated when the digital mouthpiece boots up, in order to correct for measurement offsets due to mounting operations (e.g., depending on how tightly it is screwed on, the mouthpiece rim can slightly deform the moving part of the digital mouthpiece, and thus influence the measurement results). For the trombone version of the mouthpiece, a 500g reference weight is used for this purpose. One hundred measurements are performed and weighted, to compute a correction factor. The correction factor is stored in the microcontroller's non-volatile memory, and is therefore preserved even after the power is switched off.

The system serves two purposes: on the one hand, it can be used in a simple way to collect data for scientific research, and on the other hand, it gives musicians a live insight into their playing through appropriate data representation.

2.1 The Digital Mouthpiece as a measuring device

When used to collect data for scientific research purposes, the digital mouthpiece is connected to a computer by USB-C cable via the serial interface, which allows for a significantly higher sampling rate of approximately 1.1 kHz. The sensors are pre-amplified and pre-calibrated. They provide a digital signal to the microcontroller via the I²C (pressure transducers), I²S (microphone) and SPI (load cells) interfaces. The recorded values, in this operation mode, include: three force values (in [N]), the pressure in the oral cavity (in [kPa]), the pressure in the mouthpiece (in [kPa]), the timestamp (in [s]), and the audio signal. The accuracy of the sensors is ±2% FS for the force sensors and ±1% FS for the air pressure sensors at room temperature.

2.2 The Digital Mouthpiece as a learning aid

When used as a learning aid for brass musicians, the ESP32S3 [9] microcontroller can be used to wirelessly send data, via low energy Bluetooth, to a smartphone or a tablet. This results in a reduced sampling frequency of a maximum 350Hz, depending on the smartphone/tablet used, which is still sufficient for real-time data visualisation while playing. A lower data transmission rate also reduces the computing load on the microcontroller, which makes it possible to calculate the approximate frequency of the microphone signal directly at microcontroller level.

For data visualisation, the Phyphox Application is used. It can be widely customised and is available for both IOS and Android systems. The data can also be stored in a .csv file, after playing [13]. In the current development stage, the musician can switch between different browser windows to visualise the data from the different sensors (one window per sensor: see, for example, Figure 3, where the values provided by the load cells are plotted and superposed in real-time). The digital mouthpiece also offers the possibility to use it as a MIDI controller, and thus send MIDI commands directly to a midi device via BLE according to the sensor values.

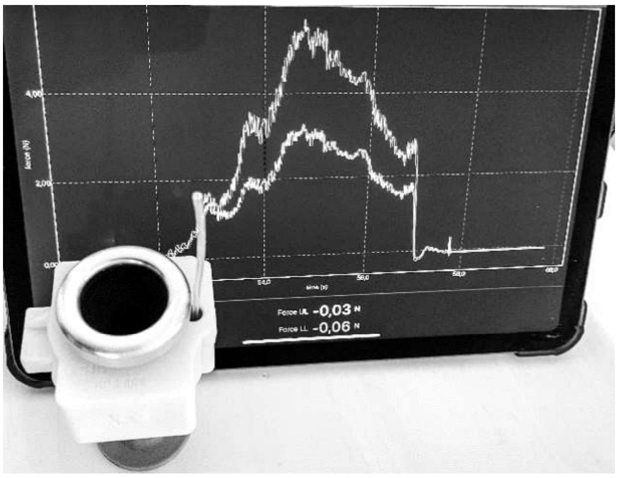

Figure 3. Digital Mouthpiece with live data visualisation

3. FIRST EXPERIMENTAL RESULTS

Experiments were conducted together with five trombone students from the Gustav Mahler University, in Klagenfurt, Austria. The students were either about to graduate or had recently graduated.

With constant dynamics and increasing pitch, the amplitude of the acoustic pressure in the mouthpiece decreased while the air pressure in the oral cavity increased. For statistically meaningful results, however, a higher number of subjects is needed, what is planned in a further study.

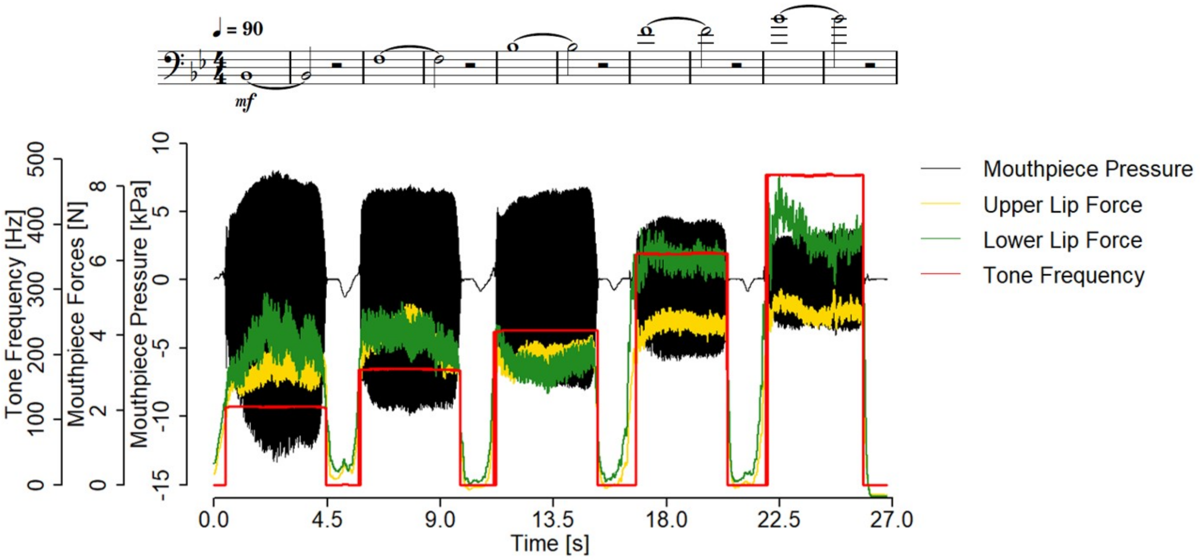

Figure 4. Played notes, and corresponding sensor data (Tone Frequency, Mouthpiece Forces and Mouthpiece Pressure for one given musician)

A sequence of notes was played (see Figure 4) using a newly calibrated and freshly sterilised digital mouthpiece, in "measurement mode". The data were recorded using a computer connected to the digital mouthpiece with a USB-C cable. The data from the pressure sensor inside the mouthpiece was used to compute the tone frequency. The forces exerted by the upper and lower lips were calculated from the load-cells data.

The data shows an increase in the exerted forces, when the pitch and intensity rise (except one musician). This phenomenon has also been observed in other studies [14–16]. In general, the lower lip exerts a greater load than the upper one (see Figure 5).

For all musicians, it could be noted that the force of the upper lip changes only slightly over the entire range and dynamics for long notes. In contrast, the force exerted on the lower lip varied greatly; four trombonists increased the force exerted with increasing pitch, while the opposite phenomenon was observed in one musician.

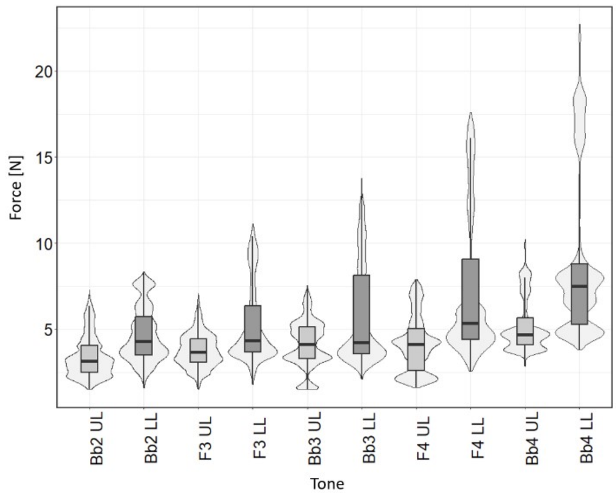

Figure 5. Forces exerted by both lips, on the mouthpiece (LL - Lower Lip, UL - Upper Lip)

4. CONCLUSION AND ACKNOWLEDGEMENT

In this paper, we presented a novel measurement system, which provides low-threshold access to useful embouchure measurement data (incl. forces applied respectively by the upper and lower lips on the mouthpiece), for both scientific and educational purposes. Experimental data acquired using the system were presented as well.

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