

Sensor and Software Technologies for Lip Pressure Measurements in Trumpet and Cornet Playing - from Lab to Classroom

T. Grosshauser, G. Troester

ETH Zurich
Electronics Lab
grotobia@ethz.ch
gerhartr@ethz.ch

A. Thul

Alte Kantonsschule Aarau
anuschka.thul@altekanti.ch

M. Bertsch

University of Music, Vienna
bertsch@mdw.ac.at

ABSTRACT

Several technologies to measure lip pressure during brass instrument playing have already been developed as prototypes. This paper presents many technological improvements of previous methods and its optimization to use this technique as “easy to handle” tool in the classroom. It also offers new options for performance science studies gathering many intra- and inter-individual variabilities of playing parameters. Improvements include a wireless sensor setup to measure lip pressure in trumpet and cornet playing and to capture the orientation and motion of the instrument. Lightweight design and simple fixation allow to perform with a minimum of alteration of the playing conditions. Wireless connectivity to mobile devices is introduced for specific data logging. The app includes features like data recording, visualization, real-time feedback and server connectivity or other data sharing possibilities. Furthermore, a calibration method for the sensor setup is developed and the results showed measurement accuracy of less than 5% deviation and measurement range from 0.6 N up to a peak load to 70 N. A pilot study with 9 participants (beginners, advanced students and a professional player) confirmed practical usage. The integration of these real-time data visualizations into daily teaching and practicing could be just the next small step. Lip pressure forces are not only extremely critical for the upper register of the brass instruments, they are in general crucial for all brass instruments, especially playing in upper registers. Small changes of the fitting permit the use of the sensor for all brass instruments.

1. INTRODUCTION

In music performance research and analysis, more and more sensor technologies were added to mainly audio and video based systems (see Ng et al. in [1], [2] and Grosshauser et al. in [3]). In this paper a further developed sensor setup for trumpet and cornet lip pressure measurement is introduced similar to Bertsch et al. in [4], Mayer et al. in [5],

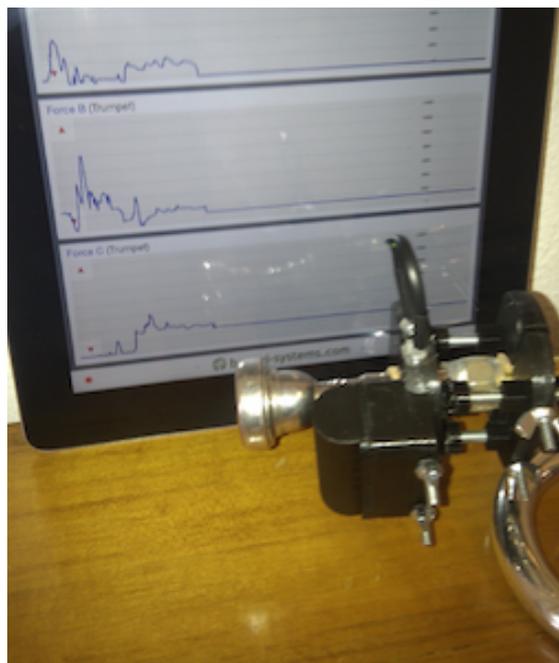


Figure 1. This figure shows an early prototype of the sensor module fixed on a trumpet and the data logging app in the background. The first row shows the sum of all three load cells and the following three rows the data of each cell.

Petiot in [6] and Grosshauser et al. in [7]. The used sensors are load cells to measure lip pressure with three triangular arranged measurement points to measure the overall lip pressure and the direction of the pressure. A 9 Degree of Freedom (9 DOF) Inertial Measurement Unit (IMU) is integrated to measure three axes of acceleration and the 3d orientation of the instrument. All sensors are integrated in a module of 60 gr of weight, which is fixed on the mouthpiece and the instrument (see fig. 1 and fig. 3). The sensor module further contains a small printed circuit board (PCB) and is connected wirelessly via Bluetooth Low Energy (BLE) to a mobile device running an app for data recording, visualization, server upload and real-time feedback (see fig. 1). In an evaluation with 9 trumpet and cornet players, the module was tested regarding usability and the influence on musicians using the module while playing the sensor equipped trumpet and cornet.

Beside the technical features and the development of a

calibration routine, one important point was to simplify the usage and installation of the complete system for simple integration into daily teaching and practicing scenarios. On the other side, the precision of the sensors and possibilities of extensive data calculation on the server side opens many possibilities in scientific experiments and evaluations. Furthermore the real-time possibilities allow applications in augmented instruments and experimental music.

2. TECHNICAL DESCRIPTION OF THE SETUP

Beside measurement accuracy the basic requirement was simple usage and usability to allow fluent integration into daily practicing and teaching scenarios. To reach this goal, the connection between sensor module and mobile device is established automatically after choosing the sensor in the app. After the module is connected the received sensor data are visualized in the app (see fig. 1). The data stream can be recorded, uploaded to a server or thresholds for real-time feedback can be set by simply dragging the line to the needed values. Several more features are available within this app to extend the range of applications and to simplify daily usage.

2.1 The Data Logging App

The app shows all available sensors and sensor channels. The individual set of channels needed for the experiments or measurements e.g. orientation only, pressure and orientation together, etc. are chosen by clicking on them. The connection is established automatically. In a second step, different visualizations can be selected and if necessary, thresholds for real-time feedback can be adjusted. The data streams of each selected sensor is recorded in a file in *.csv file format to allow further calculations in standard statistic programs. Additionally, sharing the recorded data via email, online storage service providers or server upload is possible. If the data are uploaded to a server, a newly developed web based interface provides multi-modal online data management, alignment, e.g. with audio or video recordings and data annotation.

2.2 Sensor Module

After numerous prototypes of the sensor module and the app, the final setup was completed. The sensor module consists of three miniature load cells and one 9 DOF sensor. For power supply a 3V battery is used (see no. 4a in fig. 3). In the housing (see no. 5a in fig. 3) a small PCB is integrated equipped with a BLE module for data transmission, 16bit analog to digital converters (ADCs), voltage regulators and a 9 DOF IMU.

The sensor module (see fig. 3), consists of a 9 DOF IMU with 3 axes accelerometer, 3 axes gyroscopes, 3 axes magnetometer. Based on the IMU data, yaw, pitch roll and w, x, y, z quaternions are calculated. This allows conclusions about the position and orientation and the acceleration of the instrument in all 3 dimensions while playing. The sampling frequency is up to 100 Hz. The final force resolution is below 1 gr, or below 0.01 N.

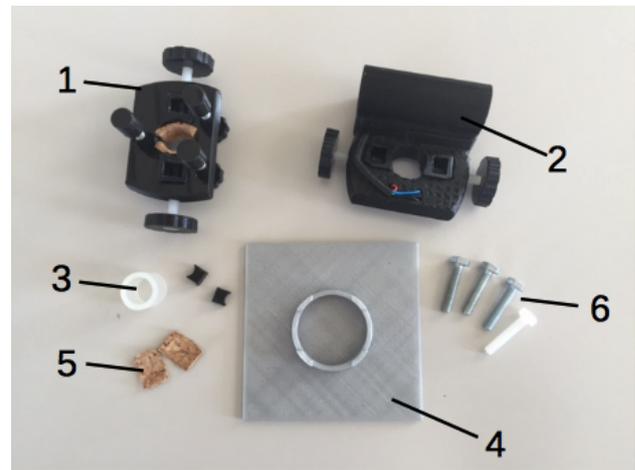


Figure 2. This figure shows the single parts of the sensor module. The part numbers are the same as in fig. 3. No. 1 is fixed on the trumpet and includes the adjustable counter-contact points for the force sensors, included in part no. 2. This part further comprises the batterie, BLE and 9 DOF IMU. Part no. 4 is an adaptor for sensor calibration and no. 3 seals the small gap between mouthpiece and trumpet. Parts 5 and 6 are further spare parts for better adjustment for specific trumpets and cornets.

2.3 Setting Up the Sensor Module

The module itself consists of 2 parts, one part including the PCB (no. 2 in fig. 2) with Battery, analog digital converters (ADCs), BLE module and the force sensors, the counter part (no. 1 in fig. 2 and no. 4a and 5a in fig. 3) with 3 adjustable contact points for load transmission. Part no. 1 and 2 in fig. 2 and fig. 3 are fixed to the mouthpiece and the instrument. The intersection between the mouthpiece and the trumpet is covered with part no. 3 in fig. 2 and fig. 3, a flexible silicon tube. The three screws no. 4 are inserted into part no. 1. These screws push part no. 1 and 2 apart from each other by touching the tip of the miniature load cells. By doing so, the mouthpiece is pushed around 1 mm out of the trumpet and the lip pressure is transmitted to the load cells only.

2.4 Calibration of the Setup

To calibrate the force sensors, on the mouthpiece of the trumpet an adaptor is fixed (see fig. 4). The trumpet with the attached adaptor is put on a precision scale. Different weights are put onto the adaptor and the sensor data are correlated to the scale read outs. The used weights range from 50 gr up to 7 kg. The overall accuracy is below 5% deviation. The deviation is mainly caused by the silicon tube between mouthpiece and trumpet. The setup is able to measure up to 7 kg.

3. EVALUATION OF THE SETUP AND RESULTS

In the following sections the evaluation is described. In this evaluation, nine students of different level, age and sex played a certain sequence of notes (see fig. 5) with their

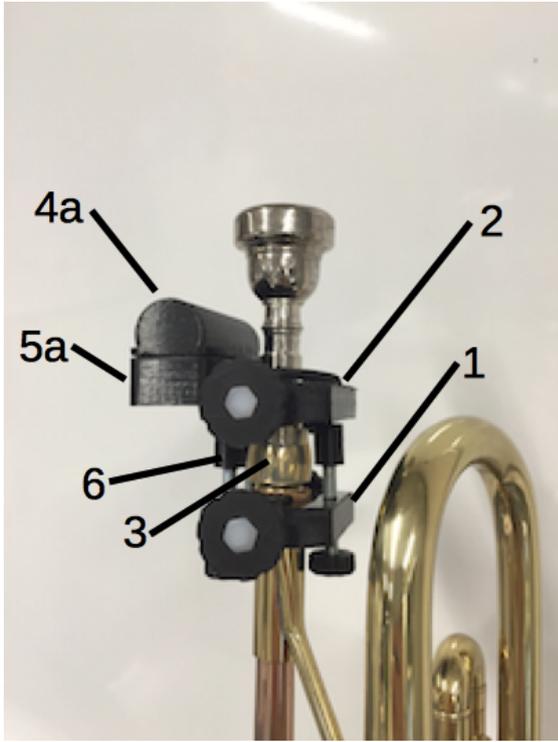


Figure 3. This figure shows the final sensor module fixed on a trumpet. The part numbers are the same as in fig. 2. 1 is the lower fixation part housing the three adjustable screws, touching the three load cells placed in part 2. These are the 3 contact points for force transmission. Between mouthpiece and trumpet there is a 1 mm gap (the mouthpiece is pulled around 1 mm out of the trumpet from the normal fixed position), bridged by 3, a silicon tube. Module 2 includes the PCB (no. 5a) with three miniature load cells, a 10 DOF IMU providing yaw, pitch roll and w, x, y, z quaternions and raw data of the 3 axes accelerometer, 3 axes gyroscopes, 3 axes magnetometer, Bluetooth based data transmission module and a battery (no. 4a).

own instrument, each equipped with the sensor module. They all played in the same room, one after the other. After a short instruction, their instrument was prepared and after a warm up phase, the given phrases were played and finally a questionnaire was filled out by each participant.

The statistical data of the participants are shown in table 1 and the measurement results in fig. 6. The complete experiment took about 20 min per test subject. All subjects played in the same tempo at 60 bpm.

The sensor fits trumpets, cornets, Flugelhorn either with piston or rotary valves. None of the participants felt hindered by the sensor setup while playing and also the played sequences were “easy” or at least “OK” according to their self- assessment. A typical pressure curve is shown in fig. 6 (professional player) and in fig. 7 (amateur player). A tendency of increasing lip pressure of higher notes is clearly distinguishable and congruent with the results of Borchers et al. in [8]. But there is also a big difference in the applied pressure, the professional player uses much less overall force and also the peaks are much lower compared to the amateur players. For the teacher, the data could give



Figure 4. This figure shows an adapter (see also part no. 4 in fig. 2) mounted on the mouth piece of the trumpet to calibrate the sensor setup with defined weights. The sensor is an early prototype of the final setup shown in fig. 3. The trumpet is placed on a highly precise scale. The sensor is calibrated and the final accuracy is specified by putting different weights between 50 gr and 7 kg on the adapter fixed on the mouthpiece.

No.	Age	Exp.	Sex	Instr.	Interfer.	Level
1	15	8	m	Cornet	no	easy
2	17	8	m	Cornet	no	easy
3	18	9	f	Cornet	no	OK
4	29	21	f	Trump.	no	OK
5	17	10	m	Trump.	no	OK
6	19	14	m	Trump.	no	easy
7	17	7	m	Trump.	no	easy
8	18	11	m	Trump.	no	OK
9	21	12	m	Trump.	no	easy

Table 1. The table shows the statistical data of the 9 participants of this study. Participant no. 4 was one professional player with a German trumpet model, the others were students (participants no. 5–9) with a piston valve trumpet model or cornet had a playing experience between 7 and 21 years. The self estimation of the level of the played sequence (see fig. 5) was “easy” or “OK” for all participants and no one felt hindered by the setup (interference “no”).

a good insight into the applied pressure, which is usually hard to see and even more difficult to quantify, especially during daily teaching routine.

Lip Pressure: Trumpet Performance Research

LiPr – Aufnahmeprotokoll (Grosshauser / Bertsch)

Player: _____ Age: _____
 Instrument: _____ Years playing: _____
 Level: [] Amateur [] Trp-Student [] Semin-Pro [] Pro
 Date _____

TASKS

(A) Open-Notes (Half-note, Half-note rest) **mezzoforte** : c1 - g1 - c2 - e2 - g2
 Metronom : 60 !

Filename: _____

(B) Open-Notes (Half-note, Half-note rest) **piano (pp)** : c1 - g1 - c2 - e2 - g2
 Metronom : 60 !

Filename: _____

(C) Open-Notes (Half-note, Half-note rest) **forte (ff)** : c1 - g1 - c2 - e2 - g2
 Metronom : 60 !

Filename: _____

(D) Music
 Metronom : 60 !

Filename: _____



Figure 5. This figure shows the sequence, every subject played during the evaluation. Typical playing scenarios with varying lip pressure are chosen. The last four notes “optional” are hard to play and the highest pressure peaks were reached.

4. PEDAGOGICAL ASPECTS AND APPLICATIONS

First of all, objective measurement and real-time data visualization of lip pressure is a complete new parameter in teaching and practicing. Already visualization itself can increase the awareness of certain problems. Based on this idea, the different live plots in the app were developed (one visualization type see in fig. 1). A second step was additional real-time feedback to inform the musician, if certain thresholds (e.g. maximum pressure in certain playing sequences) were exceeded. Certainly, every musician has her/his own playing forces, but e.g. in case of too high lip pressure the teacher can measure and visualize it or even adjust individual real-time feedback with the described set-up. Furthermore she/he can include the additional information in the daily teaching routine or additionally adjust the threshold individually for automated feedback. With these individual adjustments the student might also be able to use the system while practicing at home.

Comparisons between players (interindividual variability) can reveal the minimal force needed for certain playing techniques, and help students to relate their values to improve economic and ergonomic playing techniques. “No

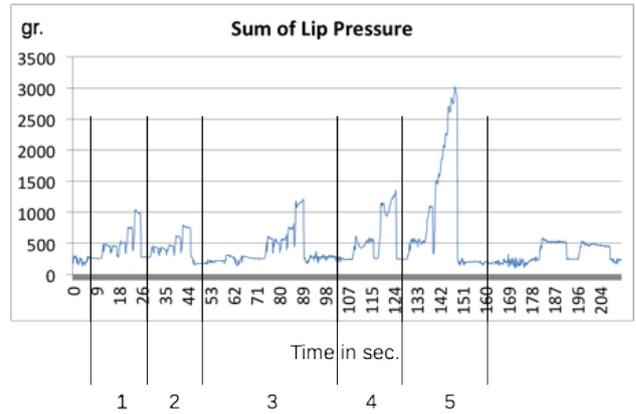


Figure 6. This figure shows the lip pressure curves of the sequence in fig. 5 of a professional trumpet player played with a piston valve trumpet. Part 1 to 3 correspond to (A) to (C) in fig. 5, part 4 is first staff, part 5 is second staff. The last four notes (“optional” end of part 5) are the most difficult one to play and a lot of force is applied.

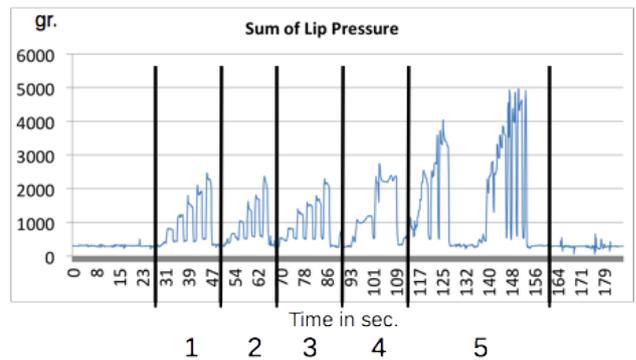


Figure 7. This figure shows the pressure curves of the sequence in fig. 5 of a student, played with a piston valve trumpet. Part 1 to 5 are the same as in fig. 6, part 5 was played two times, but not reaching the highest note. Much higher forces are clearly recognizable, with maximum peaks up to 50 N compared to 30 N of the professional player (fig. 6).

pressure” instructions of teachers have been confusing for a long time (see Wilken in [9]). Less pressure is positive, but there is no standard or correct pressure number to tell, since embouchures are always individual and have to fit physiological parameters (see Bertsch in [10]). Since the engaged amount of force for one player also depends on multiple factors (intraindividual variability) studies during different conditions can be of enormous pedagogic help. The integrated real-time feedback features allow several further applications e.g. to indicate if a playing break is necessary for relaxation, to study the difference between embouchure setups, or the importance and level of embouchure muscles.

Certain qualities in playing can only be achieved by playing “on the air”, which usually result in lower lip pressure. The basic principle is simple, too much pressure hinders the lips to vibrate and can end in a failure of the tone pro-

duction. On the other side, the higher the note, the higher the pressure. This means, between too much and “correct” lip pressure is a fine line, which can be observed and discovered with the lip pressure measurement setup presented in this paper. Since lip pressure also influence the vibration characteristic of the lips and can change the lip opening area, the control of lip forces allows also better control of the instrument sound (see Bromage et al. in [11]).

Finally this might support trumpet/cornet students to find the correct “positive” lip pressure and additionally playing with a sensor might already have a positive effect on focusing on this specific problem. The data recording and visualization further allows teachers and students long term observations and adapting the practicing scheme more individually. But also self-observations are possible, e.g. which pressure is necessary to reach a certain tone quality or simple correlations between visualization and sound might already help to find good or bad influences of certain lip pressure conditions.

5. CONCLUSION

The described setup demonstrates a promising approach, how a practical integration of sensor technologies into daily teaching, practicing and performance science and observation could be realized. The main goal was the plug-and-play idea to use the sensors needed by simply adding them into an existing setup, here the trumpet and cornet. This is a main requirement for daily use and acceptance in the music community.

The main application fields are all kinds of teaching, practicing and learning scenarios but also in music medicine, new and augment musical instruments and performance research in general. But force data furthermore provide an insight of the applied forces while playing, which opens up many possibilities in health related questions like cramping recognition or fatigue detection.

Furthermore, considering augmented musical instruments, this additional parameter may lead to several new expression possibilities e.g. for additional parameter adjustment like sound effects in real-time or manipulation of other control signals like DMX or MIDI.

Acknowledgments

Special thanks to www.bonsai-systems.com providing us the data logging app and further technical support.

6. REFERENCES

- [1] K. Ng, “3d motion data analysis and visualisation for technology-enhanced learning and heritage preservation,” in *AIKED’09: Proceedings of the 8th WSEAS international conference on Artificial intelligence, knowledge engineering and data bases*. Stevens Point, Wisconsin, USA: World Scientific and Engineering Academy and Society (WSEAS), 2009, pp. 384–389.
- [2] W. Goebel and C. Palmer, “Tactile feedback and timing accuracy in piano performance,” *Experimental Brain Research*, vol. Volume 186, pp. 471–479, 2008.
- [3] T. Grosshauser and G. Tröster, “Further finger position and pressure sensing techniques for strings and keyboard instruments,” in *New Interfaces for Musical Expression, NIME13*, 2013.
- [4] M. Bertsch and A. Mayer, “3d transducer for measuring the trumpet mouthpiece force,” in *roceedings of the Forum Acusticum Budapest*, 2005.
- [5] A. Mayer and M. Bertsch, “A new 3d transducer for measuring the trumpet mouthpiece force,” in *Proceedings of Second Congress of Alps-Adria Acoustics Association and First Congress of Acoustical Society of Croatia*, 2005.
- [6] J. F. Petiot, “Measurements of the force applied to the mouthpiece during brass instrument playing,” in *Proceedings of the SMAC03 (Stockholm Music Acoustics Conference 2003)*.
- [7] T. Grosshauser, B. Hufnagl, G. Tröster, and A. Mor-nell, “Sensor based hand weight and pressure measurements in trombone playing,” in *SMAC Stockholm Music Acoustics Conference*, 2013.
- [8] L. Borchers, M. Gebert, and T. Jung, “Measurement of tooth displacements and mouthpiece forces during brass instrument playing,” in *Medical Engineering and Physics*, vol. 17, 1995, pp. 567–570.
- [9] D. Wilken. [Online]. Available: www.wilktone.com/?p=1936
- [10] M. Bertsch, *Collected Papers in Musical Acoustics 1995/2003*. Schriftenreihe des Instituts für Wiener Klangstil - Musikalische Akustik Universität für Musik und darstellende Kunst Wien. Band 6 (2003). [Online]. Available: [http://personal.mdw.ac.at/bertsch/MB-PDF/2003e_MB_Collected-Papers-\(Habil2\).pdf](http://personal.mdw.ac.at/bertsch/MB-PDF/2003e_MB_Collected-Papers-(Habil2).pdf)
- [11] S. Bromage and M. Campbell, “Open areas of vibrating lips in trombone playing,” in *Acta Acoustica*, 2010.