Measuring Pitch with Historic Phonetic Devices

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Abstract

Measuring pitch is one of the most important but also most difficult tasks in experimental phonetics. It is interesting to study how the difficulties have been solved in the times before the computer was introduced in the phonetic laboratories. In this paper, this is discussed using a number of exhibits of the acoustic-phonetic collection of the Dresden University. There will be a small exhibition of historic devices at the conference Speech Prosody 2006. This paper is intended to accompany the exhibition.

1. Introduction

On the occasion of Speech Prosody 2006, the Dresden University of Technology does not only host the conference and present some results of the current work in prosody research. There is also the opportunity to present some exhibits from the historic acoustic-phonetic collection of the university which are related to early procedures in pitch measurement.

Some details of the acoustic-phonetic collection have been published already [17-19]. The collection was essentially enlarged in 2005 when it was united with the former collection of the Phonetic Institute of the Hamburg University (cf. the catalogue [20]). Phoneticians from Hamburg (Panconcelli-Calzia, Schneider, Stilke) and also from Berlin (Gutzmann, Wethlo) acted as pioneers in the investigation of pitch. The Dresden collection includes apparatuses for pitch measurement from both origins. They help us to realize how much time and effort was required in those times for recording, measurement and pitch calculation.

2. Pitch as a research topic in the last century

Rousselot has early shown that phonetics is an experimental science. In Germany, his scholar G. Panconcelli-Calzia [1] introduced the experimental phonetics as scientific field in Hamburg like Gutzmann and Wethlo did in Berlin. There was a special interest at the beginning of the last century in studying the pitch in foreign languages, especially tone languages. From the physiologic point of view, different methody like photography, cinematography, and X-ray methods were available for that purpose. For physical investigations, the kymographion was combined with either a mouth funnel or a larynx capsule. The kymographic recordings showed the drawback that they could not be reproduced. Therefore, a combination of the kymograph and the phonograph was frequently applied, and a lot of phonographic or gramophone recordings were collected and investigated in the phonetic laboratories.

After doing the recordings, the curves had to be measured for interpretation. The pioneers of pitch research did it by comparing it to the recording of the vibration of a tuning-fork which was calibrated to, e. g., 100 Hz [2]. This was very time-consuming, and the devices which we will consider in Section 3 had been designed to simplify the procedure and to enhance the accuracy of the interpretation.

In this way, it was possible to proceed from a qualitative description with terms like rising/falling etc. to an exact measurement of the pitch. Figure 1 shows an example where two words were produced with pitch contours having nearly the same shape but different pitch frequencies.

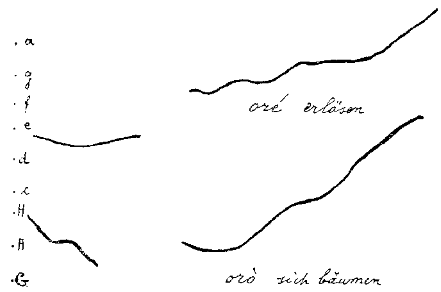
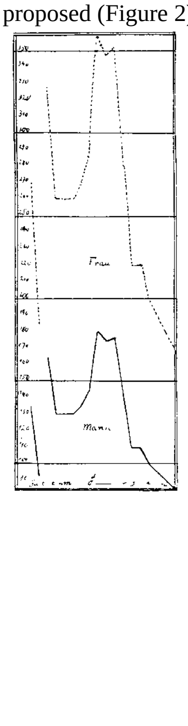


Figure 1: *Example for a pitch contour in a tone language (Hottentot language, Bergdamara dialect, from Panconcelli-Calzia [2]).*

3. Mechanical pitch measurement devices

3.1. General remarks

In the simplest case, the result of the pitch measurement is a graphic representation of the frequency vs. the time. Because this linear representation does not correspond to the human perception basing on an octave scale, a logarithmic scale was proposed (Figure 2).



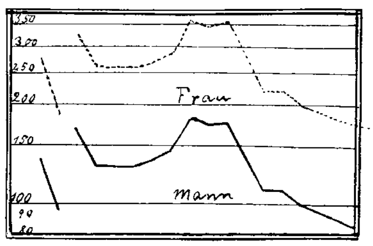


Figure 2: *Pitch contours (male vs. female) presented by Gutzmann (from [4]) in linear scale (left) and logarithmic scale (right).*

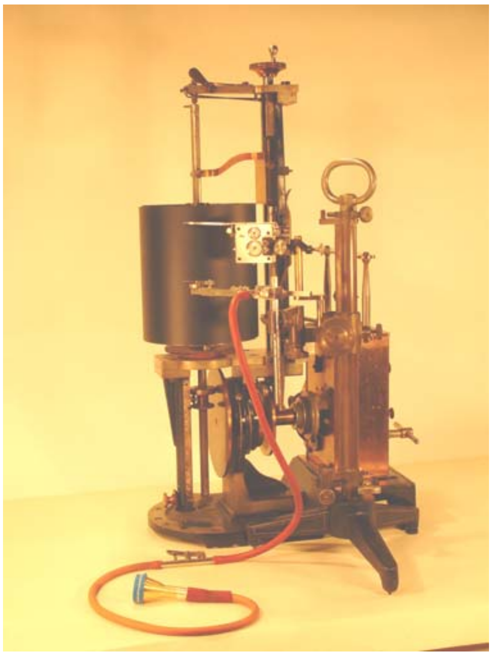


Figure 3: *Arrangement for recording the "throat sound" as described by Panconcelli-Calzia. Photograph of the equipment in the historic collection of the Dresden University (from [19]).*

Wethlo [3] discusses the measurement methods which were available in the pioneering time of pitch measurement, among them the photographic registration, the phonographic method [5], or the method of Marbe (cf. Section 3.4). Because of a number of drawbacks of these procedures, the traditional method where one or more writing capsules (Marey's capsules) transferred the pitch values onto the sooted paper of a kymograph, remained to be most widespread. A kymograph which is equipped with all accessories needed for recording the "throat sound" is shown in Figure 3.

It was very essential to provide a constant revolving speed of the kymograph. A length difference of 0.1 mm per one vibration leads to an error of one or two semibreves. The Leipzig manufacturer Zimmermann produced the first kymograph with two speeds (100 or 200 mm/s) which revolved with high accuracy.

3.2. Pitch measuring apparatus by E. A. Meyer

The whole procedure of converting kymographic waveforms into pitch contours consisted of the following steps which had to be performed with highest accuracy:

1. Measuring the period lengths using a microscope
2. Calculating the logarithms of the period lengths
3. Drawing the different period lengths along an abscissa
4. Drawing the logarithms of the period lengths as ordinates of the respective points of the abscissa
5. Interpolating the ordinate points to a curve
6. Converting the ordinate into a musical scale basing on the speed of the cylinder surface at the time of recording the waveform

This work was extremely time-consuming. The Stockholm scientist E. A. Meyer constructed a mechanical aid for supporting it without losses of accuracy (Figure 4).

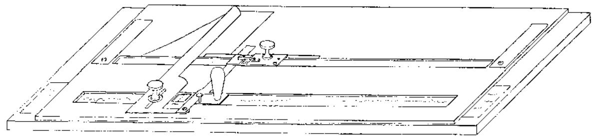


Figure 4: *Pitch contour measuring apparatus of E. A. Meyer from the original publication [6].*

The function of the device is basing on a transformation of a horizontal movement into a vertical movement using a fixed perpendicular guide [6]. Meyer indicates that the accuracy is depending on the precision of the parts of the apparatus as well as on the skill of the user. The device is estimated to save 80 % of analyzing time. Figure 5 shows an example for the pitch contour of an Italian word. The perpendicular lines are marking the sound boundaries which were determined basing on a mouth breathing curve which was recorded simultaneously.

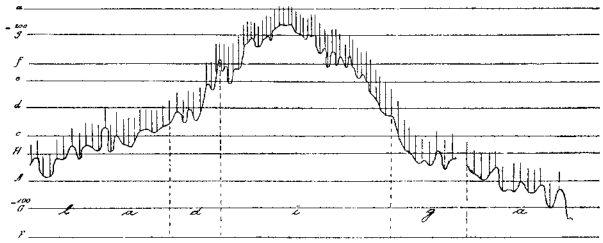


Figure 5: *Pitch contour ('la diga') produced with Meyer's apparatus (from [6]).*

Following the first experiences with Meyer's apparatus in phonetic laboratories, an improved model was developed by Schneider [7]. Its mechanic parts were more robust, and some accessories like a magnifying glass, paper rolls for continuous work, and a so-called length-comparator were added. The measurement was possible with an accuracy of 1/100 mm. For further discussion, see Stilke [8] and Panconcelli-Calzia [9].

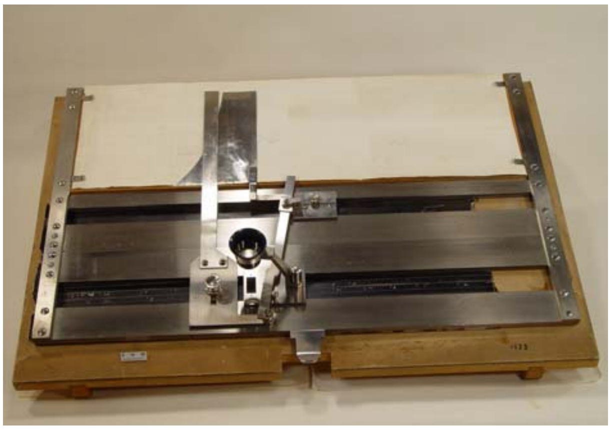


Figure 6: *Improved version of the pitch contour measuring apparatus. Original device from the Hamburg Phonetic Institute, now in the Dresden collection.*

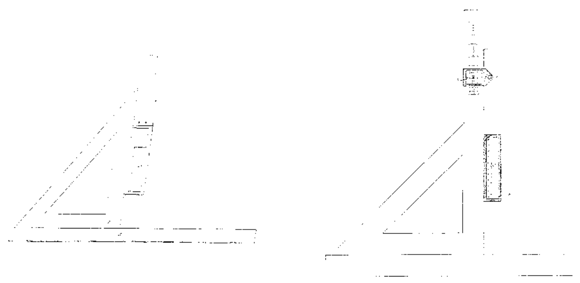


Figure 7: *Two apparatuses for measuring pitch from A. Fürstenberg [10].*

3.3. Pitch measuring apparatus by A. Fürstenberg

Although Meyer’s apparatus produced excellent results, it had some drawbacks (high price, weight, poor suitability for field research). Some years later, two pitch measurement devices with simpler design were published by Fürstenberg [10]; cf. Figure 7. With this arrangement, the logarithm is calculated using a glass template having a number of logarithmic curves etched in it. It seems that the usage of the device was rather complicated, however.

3.4. Pitch measurement by vibrating flames

Another method for measuring pitch invented by K. Marbe used a smoking acetylene flame and produced sharp circles from soot. Following a discussion of Wethlo [11], the accuracy of this method which is potentially very high decreases if the signal is non-stationary like speech.

3.5. Pitch measurement using templates by F. Wethlo

Wethlo aimed to simplify the exact but complicated procedures. He developed a quick procedure which he called ‘simplified phonetic pitch measurement’ [13]. The basic equipment is still a kymograph with a surface speed of exactly 100 or 200 mm/s, combined with either a mouth or a throat sound recorder.

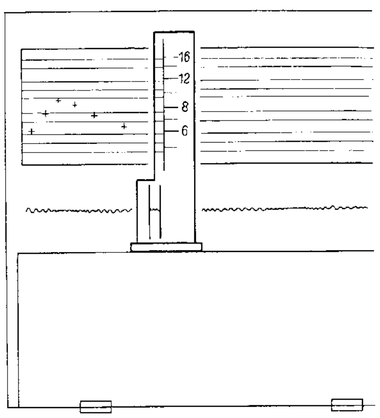


Figure 8: *Drawing-board with a shiftable pattern [13].*

(a)

(b)

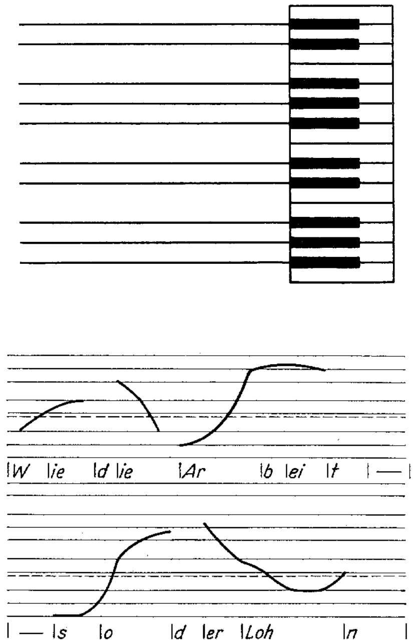


Figure 9: *Example for the recording technology proposed by F. Wethlo (from [13]). (a) Keyboard-like line system for pitch recording, (b) measured pitch contour.*

The device itself (Figure 8) consists of a special template with a pitch scale, a drawing-board with an edge for positioning, and a paper strip with pitch lines for recording the final result. The pitch lines on the paper are arranged according to the piano keyboard with a distance of 2 mm per semitone (Figure 9a). Two vertical lines at the transparent template delimit a 5 mm long section of the waveform. The result is obtained by counting the number of vibrations in this section, looking up this number at the scale of the template, and marking the corresponding pitch on the paper strip at the edge of the template.

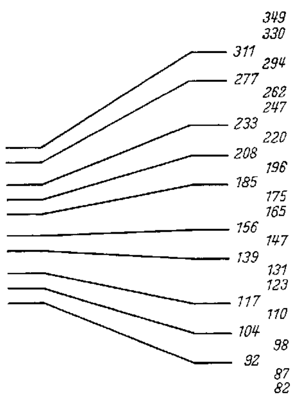


Figure 10: *Template for measuring the frequencies (from F. Wethlo [13]).*

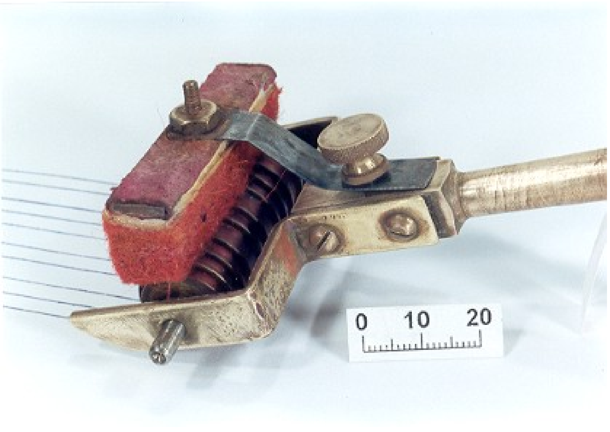


Figure 11: *Printing roller for the production of the keyboard-like lines. Photograph of the device in the Dresden collection.*

Wethlo improved this approach until the 1950-th [14]. In his opinion, the keyboard-like line system allowed a quick orientation also for unmusical users. By means of a simple template (Figure 10), the frequencies were obtained quickly. The lines were produced on endless paper using the roller shown in Figure 11.

Instead of counting the number of periods per segment, the measurement of the length of single periods was also possible. For this purpose, a measuring projector with a magnification of 10 was developed (Figure 12). The length was measured on the matt screen of the projector using a special vernier gauge with a nonius of 1/10 mm. This results in an overall measuring exactness of 1/100 mm.

Figure 12: *The original aids from Franz Wethlo for easier interpretation of the recorded waveforms. This equipment consisting of a measuring projector and a vernier gauge is now in the historic collection of the Dresden University (from [19]).*

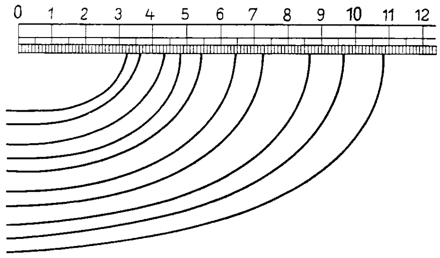


Figure 13: *Template for converting the period length in the pitch marking (from F. Wethlo [13]).*

Now, another template (Figure 13) could be used for converting the measured length from the gauge into a pitch value on the keyboard-like lines.

4. Pitch measurement devices of the 1930-th

Due to the growing importance of the electronic valve in the 1930-th, new methods for pitch analysis evolved. Because the main focus of our paper is on the pre-electronic devices, we will give only a short overview.

4.1. Pitch recorder by Zwirner and Engl

E. Zwirner was engaged in developing devices for automatic pitch recording [15]. Together with Engl, he constructed a recorder which worked with a microphone. The microphone signal is amplified and controls an acoustic system as well as an electromagnetic field which acts on a system of 30 chords which are tuned in semitone distance. The resonance of the chords is photographically registered along with a time marking. Obviously, this interesting device was too complicated for practical application.

4.2. Tongue frequency meter by C. W. Hickman

Another electromechanical solution utilizes the resonance of metallic tongues similar to the well-known tongue frequency meter. In this device (Hickman 1934), the movement of the tongues is registered by light beams which are influenced by small mirrors coupled to the tongues. The method suffered from a slow transient behavior.

4.3. Pitch measurement by J. Tiffin

In the same year (1934), J. Tiffin proposed to control a neon lamp with the amplified speech signal. The changing light was used for a stroboscopic recording. This device showed also problems with fast changing signals.

4.4. Undelayed recording of melody curves by Grützmacher and Lottermoser

A very successful arrangement was proposed by Grützmacher and Lottermoser in 1936 [16] and widely applied in the following years. The amplified speech signal acts upon an non-linear (quadratic) stage which produces difference tones. A chain of filters isolates the pitch frequency which is rather free of harmonics. This signal triggers a thyratron generator which, in turn, controls an oscillographic display.

5. Conclusion

We have shown that the requirements in language research produced rapid progress in pitch measurement at the beginning of the 20th century. The kymograph was the predominant device, and a number of aids had been developed to extract the pitch contour from the kymograms. Essential contributions came from the phonetic laboratories in Hamburg and Berlin, and we have shown in Section 3 that we are able to demonstrate this development using exhibits which are now in the acoustic-phonetic collection of the Dresden University.

Although the mechanic devices have been used until the 1950-th, the development of electronic devices changed continuously the equipment of the phonetic laboratories. We mentioned some early examples in Section 4. The method of Grützmacher and Lottermoser was further refined, and the progress in filter design enabled hardware solutions for the multi-channel analysis. New approaches for displaying and registering the results were designed. Many details of this development can be found in the fundamental book of W. Hess [21].

Finally, the introduction of processor controlled devices in the laboratories enabled the application of sophisticated algorithms to large amounts of speech data. We should not forget, however, the knowledge, skill, and patience which were required for the pitch analysis in former times.

6. Acknowledgement

The authors want to thank Dr. Rolf Dietzel for taking the photographs. His series of photographs of the Dresden collection (but not yet including the new exhibits coming from Hamburg which are described in [20]) can be found at www.ias.et.tu-dresden.de/sprache, clicking there at the link "Museum". Furthermore, we want to thank all persons who have supported the installation of the Dresden collection throughout the last years.

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