How Microtonal is a Well-Tuned Concert Grand Piano?

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Introduction

The core question of this paper is how accurate the tuning of a well-tuned concert grand piano is. The underlying experiment is a direct extension of previous studies [1] [2] centering on methodological issues concerning validating tuning accuracy [1], and measuring microtonal accuracy of virtual instruments respectively [2]. After first presenting a series of measurements, we focus on exemplary details and relate the final outcome to that of the virtual piano presented at DAGA 2013. A more detailed version of the paper will be available online [3].

Setup and Methods

The minimization of external influences to the measurements has been given high priority throughout the inception of our microtonal validation series [1]. We thus applied the very same, already validated and tested experimental setup. That in turn makes a direct comparison with last years' virtual piano (Pianoteq software synthesizer) tuning measurements possible. The interested reader is directed to the publication [2] for details of the setup incl. all measurement and preprocessing parameters. Following is a very brief summary of the steps involved: The complete pitch gamut of a Steinway D concert grand piano is recorded directly after the tuning process preparing public concerts in the Curt-Sachs Saal of the Staatliches Institut für Musikforschung. Each recording consists of 88 piano pitches in the way that each key is depressed for 6s followed by 6s silence, captured by ORTF condenser microphones. Subsequently the sound file (2 channel 192 kHz, 24 bit) is monoized, segmented with a MATAB rms-dependent script and analyzed via Praat. The fundamental frequency is calculated with the F0 autocorrelation function of Praat (for all details see [2]).

Two aspect are changed in comparison to the setup used in the last publication: Firstly, we had to include a recording chain to the measuring setup prior to the analyzing procedure, and secondly, a human player is added. How both factors are influencing the results will be analyzed in later experiments as are perceptive and cognitive implications. Here we focus deliberately on the signal description layer with measuring the fundamental frequencies of piano tones.

Results

Results A: Measurements of 16 fresh tunings

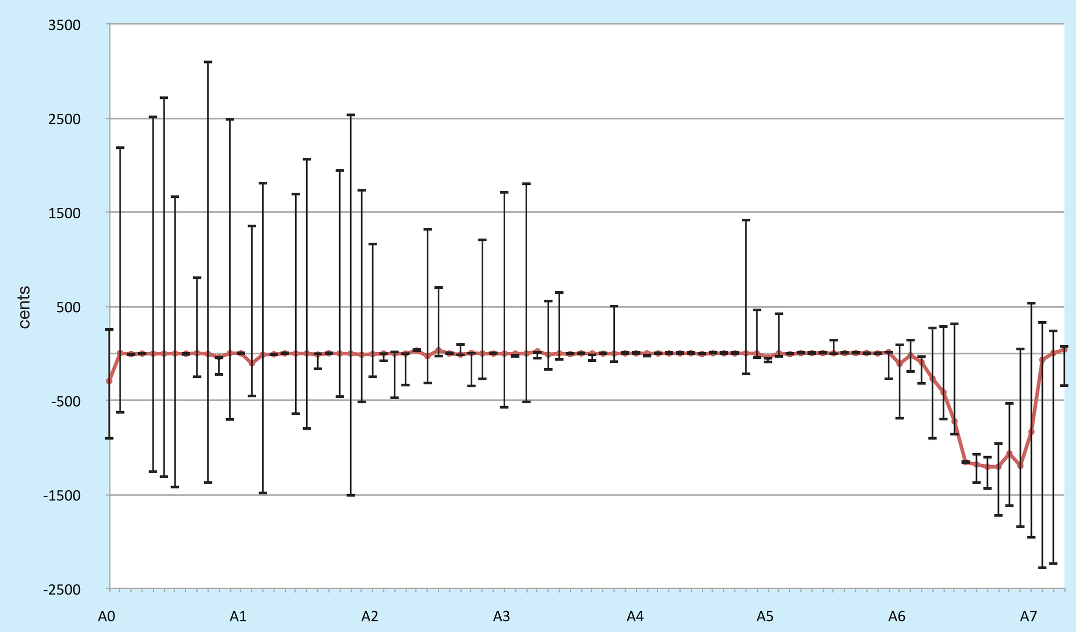

Fig. 1: Measurement of 16 distinct fresh piano tunings: Averaged F0 and measurement ranges. The y-axis represents the deviation from reference in cents. The x-axis represents the complete frequency range of the concert piano.

The analysis of the series of measurements (n=16) is depicted in Fig. 1 and 2. Interestingly, outliers (up to roughly 3000 cents) are not everywhere and seem to be not equally distributed (Fig. 1). Remarkable areas are the smooth regions around A4 and A5-A6 and the downturn from A6 on associated with large ranges but within also a zone with notably small measuring ranges.

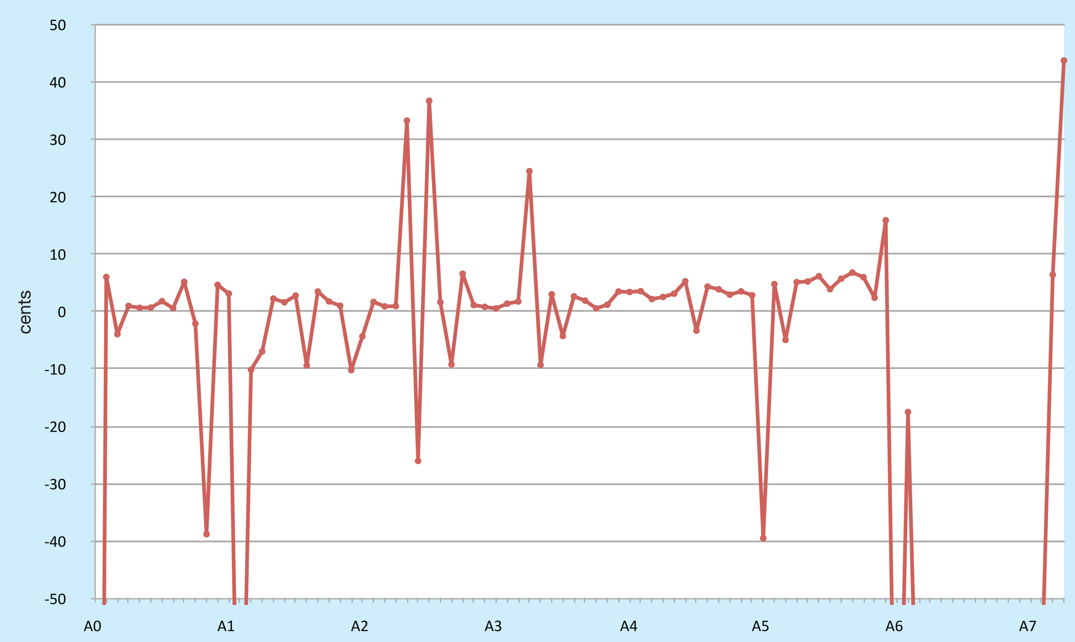

Fig. 2: Zoomed 16 averaged F0 measurements (details cf. Fig.. 1).

The downturn area is possibly indicating a measuring- or stimuli related artifact leading to a result approx. one octave (but notably less than; cf. Results D) below the expectancy value. Figure 2 depicts a zoomed window illustrating how most values average around the expectancy value within 10 cents deviation with outliers not exceeding 40 cents in the mid frequencies.

Results B: Selection of the best-fit piano tuning

The single tuning with statistically least deviation to the expectancy had been chosen for further examination and later reprocessing (see Results C). Figure 3 shows a smooth

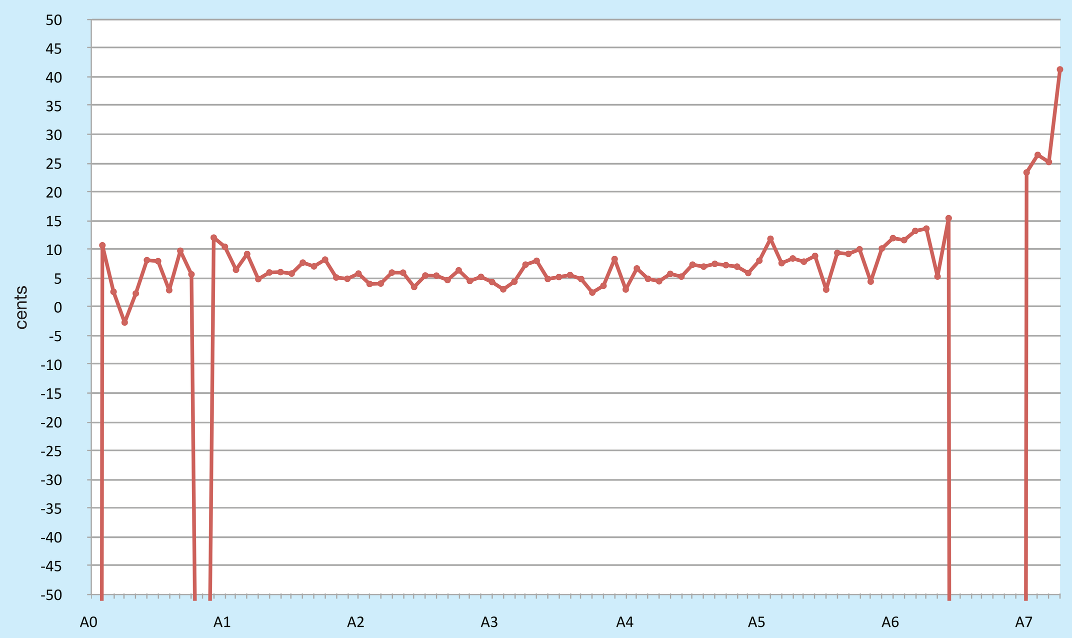

Fig. 3: Single best-fit piano tuning (zoomed deviations from reference values in cents).

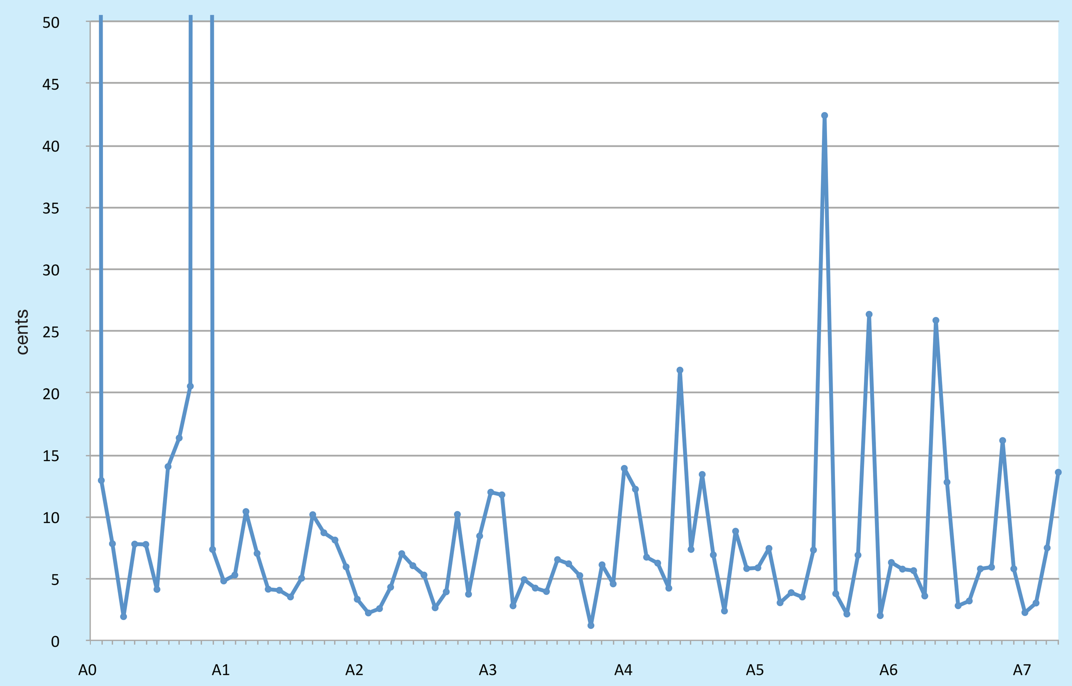

Fig. 4: Intra-note ranges in cents.

fluctuation around 5 cents (indicating an offset) with outlier areas below A1 and over A6. Intra-note ranges are depicted in Fig. 4 that exhibits a similar picture with fluctuations around 5 cents and respective outliers. The ranges' outliers are excessive only in the lows, likely indicating more plausible measuring errors in that area and a stimuli related problem in the highs (with below 30 cents ranges).

Results C: Data reprocessing & comparison with a virtual piano

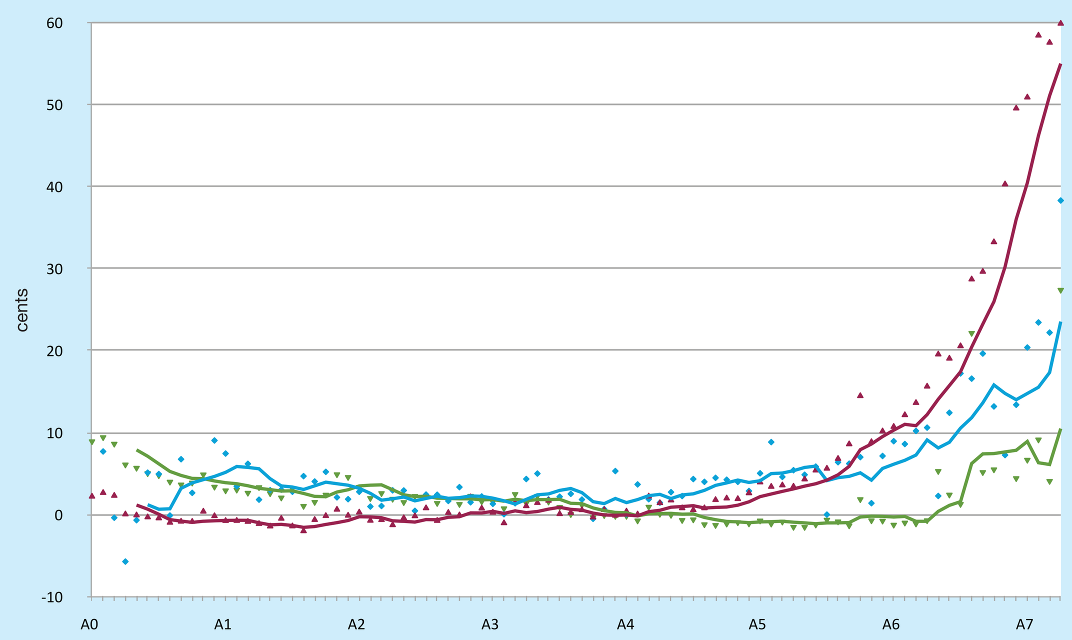

Fig. 5: Comparison of measured tuning accuracy normalized to A4 of a virtual piano (2 Pianoteq tunings with octave stretching set to 1) and the best-fit real piano tuning. Lines are 5-Sample moving averages of the measured data indicated with the colored symbols. Red = Pianoteq equal tuning; Green = Pianoteq flat tuning; Blue = real piano.

Three aspects were changed for the sake of uncovering possibly meaningful hidden data in the series of measurements. Firstly, outliers were eliminated (2 Samples), secondly, the suspectedly erroneous measurements were re-calculated as being an octave higher (6 Samples), and lastly, smoothing of suspected measuring noise had been carried out. Additionally we normalized to A4, as different reference frequencies had been discovered (442 Hz

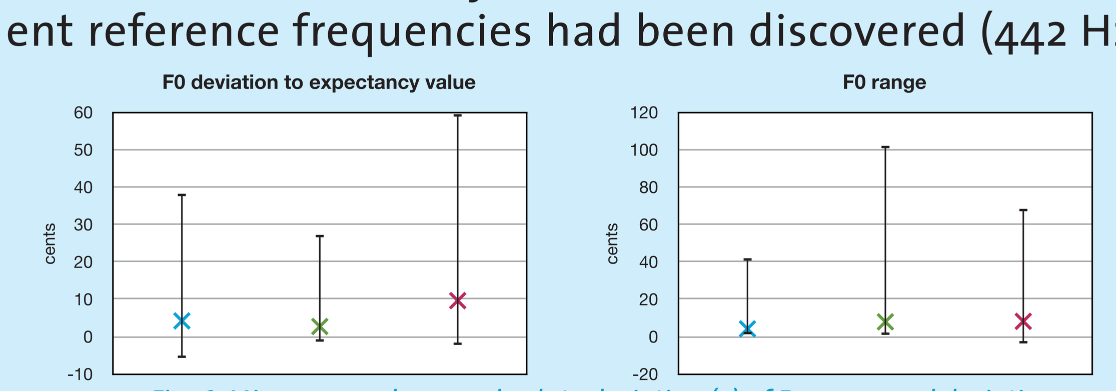

Fig. 6: Min, max, and mean absolute deviation (x) of F0 range and deviation in cents. Colors according Fig. 5 color-scheme.

for the piano; 440 Hz for Pianoteq) incl. a 5 cent offset (cf. Fig. 3). The thus resulting graphs are indicating comparable behavior for the tunings of both, real and virtual pianos: Notice e.g. tuning accuracy within 10 cent below A6, and ascending trends for the highest two octaves (Fig. 5). Core statistics for deviation and intra-note ranges underline the similarity of real and virtual piano, for the latter especially relating to the flat tuning (Fig. 6).

Results D: Octave stretching

Analyzing solely the raw measurements (cf. Fig. 1 + 2) there is no indication of octave stretching tendencies. That said, a slight trend could be visually inferred by neglecting the highest octave behavior and abstracting from the outliers (Fig. 3). Statistical foundation is given through the reprocessed data. Here (Fig. 5 blue) a clear trend ascending from A4 on culminating to an octave approx. 20 cents too high is apparent. In the lows a less prominent trend is observable too, raising to an A1 approx. 5 cents too high. Combined, a U-shaped octave stretching is observable as has been the case with both virtual piano tunings analyzed (Fig. 3; [2]).

Results E: Overall statistics revisited

Besides the notion of dimensional comparability of the graphs' underlying behavior for both real and virtual piano, the measured piano tuning lies mostly in between both virtual tunings. The real piano correlates statistically higher with Pianoteq's equal tuning (0.85) than compared to Pianoteq's flat tuning (0.56) or between equal and flat (0.51). That finding indicates a possible contribution to the open question regarding intricacies [2] of Pianoteq's octave stretching parameter and -behavior. It is worth to mention that even without the repro-

	real piano (best tuning)				virtual piano (Ptq flat 1.0)				virtual piano (Ptq equal 1.0)			
	Range [Hz]	Range [Cent]	Dev. [Hz]	Dev. [Cent]	Range [Hz]	Range [Cent]	Dev. [Hz]	Dev. [Cent]	Range [Hz]	Range [Cent]	Dev. [Hz]	Dev. [Cent]
Mean: Freq.range: a0-a5	1,77	54,05	0,56	-15,70	0,63	4,10	-0,86	2,27	0,58	4,02	-0,83	0,07
Mean: Freq.range: c1-a6	2,59	27,90	1,79	3,60	1,04	4,16	-1,68	1,47	0,90	3,94	-0,60	1,14
Mean: complete range	4,13	40,14	-92,85	-88,35	10,76	23,40	-4,70	0,45	11,22	8,57	8,53	6,71
min	0,04	1,24	-1652,91	-1189,76	0,02	0,81	-327,01	-183,24	0,02	0,49	-2,28	-2,28
max	33,87	1438,73	101,46	41,27	182,01	1315,22	51,36	27,52	154,81	68,78	130,93	59,58
MAD	4,52	63,51	183,27	174,74	16,56	33,63	7,90	4,93	17,55	8,09	15,19	9,58

Fig. 7: Selected statistics regarding range and deviation from reference for both, best-fit real piano and virtual piano tuning.

cessing of data, raw measurements provide meaningful statistical markers (Fig. 7) for interpreting the tuning accuracy of a well-maintained concert grand piano. Intra-note microtonality is statistically present with the amount of roughly 28 cents over 5 octaves, inter-note microtonality calculates in the same region to 3.6 cents.

Conclusion

It turned out that the initial question of tuning *accuracy* appeared inappropriate for two reasons: Firstly, human piano tuners seem to detune the pitches *intentionally* and secondly that very detuning is carried out in a *non-codified* manner. Furthermore it has been pointed out in the preceding study [2] that the phenomenon of octave stretching adds an amount of "detuning" to a virtual piano's tuning that is substantially greater than what microtonal theory and practice generally demand. The results of this experiment rises the question whether it makes sense to attribute single fixed frequencies to the keys of a piano. The measurements unveil the concert piano's sophisticated time-variant complex system dynamics for that a concept of inherent microtonality seem more appropriate than the common practice of linear and static ways of pitch abstraction.

According to our measurements, a real piano tuned by a human tuner can be described as being categorically equally accurate or microtonal as a virtual computer controlled counterpart. If one prefers to cite just the raw numbers, a real concert grand piano offers better than 4 cents measured tuning accuracy over the five middle octaves. That number seems thus also its limit for the pragmatic use for microtonality in composition and experiments.

References:

[1] Klouche, Timour, Teresa Samulewicz, and L. Jakob Bergner: Validation of computational tuning systems. In: Fortschritte der Akustik – DAGA 2012. Vol. I, 193–194. DEGA Berlin 2012.

[2] Klouche, Timour, Teresa Samulewicz, and L. Jakob Bergner: Measuring the accuracy of microtonal synthesizers: Pianoteq & Vogue. In: AIA-DAGA 2013, Proceedings of the International Conference on Acoustics, Merano. 279–282. DEGA Berlin 2013. extended online version: http://www.sim.spk-berlin.de/accuracy_of_microtonal_synthesizers_1344.html

[3] http://www.sim.spk-berlin.de/microtonality_of_piano_tuning_1478.html