Piano**Lab**

Ver.mob
24.07.2020

User manual

Contents

Introduction

PianoLabM – is a mobile version of the program PianoLab to tune and analyze piano for the Android platform.

PianoLab simplifies piano tuning using such tools as automatic calculation of the optimal frequencies of the temperament zone taking into account the inharmonious of the strings, visualizing the spectrum and analyzing the harmonics of a particular note, analyzing the scale by the curves of inharmonious, intervals, etc.

Key features

- spectral analysis and display of an audio signal in real time, measuring the frequency of sound with an accuracy of hundredths of a hertz,

- automatic calculation of the plan of the optimal tuning of the instrument for the temperament zone, taking into account the inharmonious of the strings,

- automatic selection of the frequency of its harmonics in the spectrum of the sound of the pressed note (the number of analyzed harmonics is 5),

- saving a snapshot of the signal spectrum for visual comparison of the spectra of two notes (for setting unison),

- saving information about the scale of the instrument to a file, loading information from a previously saved file,

- others: peak retention, amplitude and frequency scaling, etc.

Scaling tools allow you to analyze in detail any part of the spectrum. This is especially useful when analyzing the harmonics of an input note.

It should be especially emphasized that the program contains a module for finding the optimal solution for the temperament zone.

Hardware and software requirements

- Operating system – Android 4 and higher,

- Sound module – any, including built-in (on the motherboard),

- Microphone – any, but a microphone with a frequency range of 10 Hz - 20 kHz is desirable for full tuning of the scale. If your microphone does not support the entire range, then according to the tuned middle part of the range - frequencies from 100 to 4500 Hz, which, as a rule, any microphone supports, the rest of the scale is tuned: according to the upper harmonics for bass and the lower harmonics for treble.

Program installation

The PianoLabM installer can be downloaded from the website https://PianoLab.ru/ in the download section.

The latest versions of Android have increased protection during installation and initial launch of the program. With all the warnings issued by Android protection, you must agree and continue the program.

Appendix 1 contains some snapshots of warning windows.

Appendix 2 provides a description of some of the concepts used in the program.

Appendix 3 description of program settings

Description of the main program windows

The program can use two types of displaying information on the screen (conventionally, **H** and **HFS** configurations):

- **H** (harmonics and narrowing of the spectrum for the current note and harmonics)

- **HFS** (harmonics, frequencies and spectrum)

The **H** configuration is more convenient for devices with a small screen – 4-6 inches,

and the more informative **HFS** configuration is for large screen devices – 7-10 inches.

After installing the program, the default configuration is H.

The choice of configuration can be done after starting the program from the menu by pressing the **M** button, and then, **Switching configurations**.

After installing the program, the default configuration is **H**.
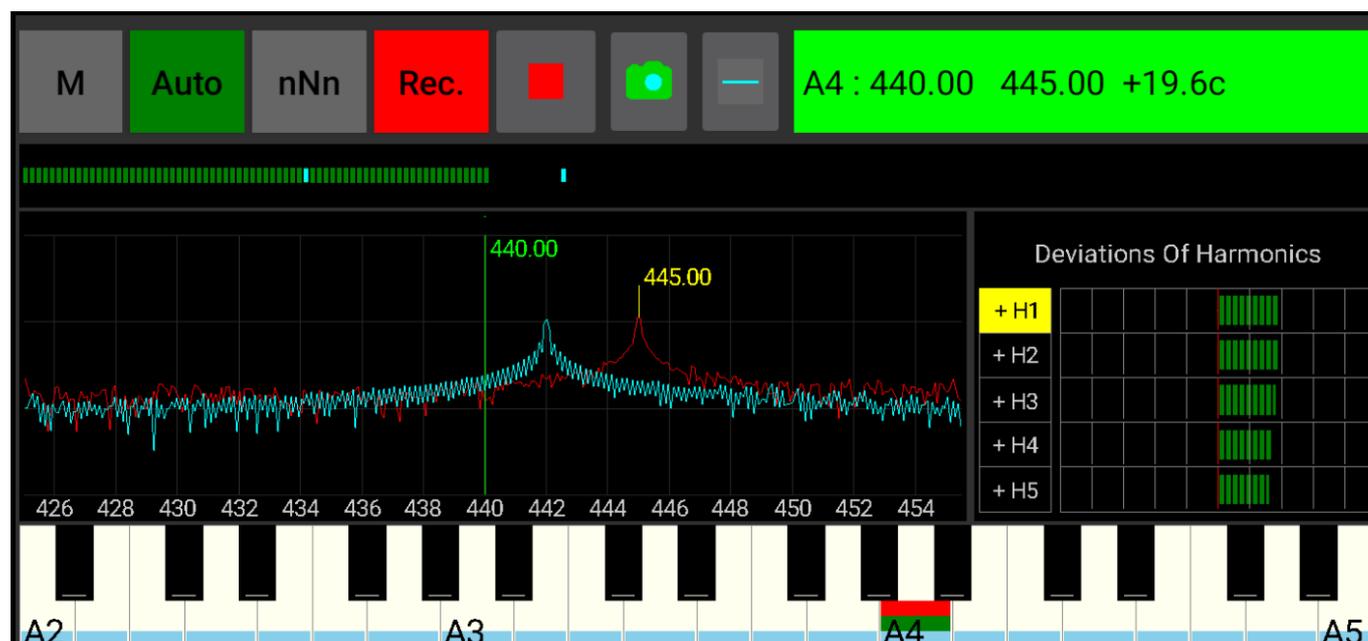
The choice of configuration can be done after starting the program from the menu by pressing the **M** button, and then, **Switching configurations**.

H configuration description

The window is split vertically into four fragments:

- Control buttons.

- Input level.

- The spectrum of the current note and on the right is the harmonics pane.

- Virtual keyboard.

Control buttons

- **M** - call pop-up **Menu**.

- - turns on / off **Auto** detection of notes.

- - enable / disable **Auto** detection of notes, only **adjacent** to the current note or notes throughout the range.

- - enable / disable note **Recording**.

- - **Start / Stop** of sound signal input.

- - enable / disable spectrum **Snapshot**.

- - turns on / off the display of the **Cutoff Line (COL)**.

- **Information field –** to display the name of the current note, harmonic frequencies with the optimal and real frequencies and the difference between them in cents. **When a note is recognized, the background of this window is highlighted in bright green.** It is also used to display some program messages. When clicked, a pop-up window appears with the following information:

  ◦ B1 – base1 (left border of the temperament zone),
  ◦ B2 – base2 (right border of the temperament zone),
  ◦ A4 – base note frequency,
  ◦ Fs – sampling rate,
  ◦ FFTsz – value of the Fourier transform analysis block,
  ◦ Sres – spectral resolution value in Hz.

The buttons have two states – **on** or **off**. In the on state the background of the buttons is green,

in the off state it is gray. An exception is the button (**Record**) - the background of this button turns red when enabled.

Input signal level

Has two markers. The right marker (**MAXs**) defines the threshold value of the signal, after exceeding which, the recognition of the note in the input signal begins. The left marker (**MINs**) defines the minimum threshold that determines the end of signal analysis. The position of the right marker can be changed by sliding your finger in this strip from left / right and vice versa.

The spectrum of the current note and harmonic

The length of the spectrum is 120 cents, 60 cents to the left and right of the optimal frequency of the current note and harmonic. Selecting a note is done from the virtual keyboard, and selecting a harmonic by moving the frame up and down in the right sub-window with a gesture. This fragment shows the marker of the optimal frequency – a vertical line of bright green color. If a spectrum snapshot was taken, the spectrum snapshot is also displayed in bluish color. And if, during the input process, the note was recognized, then the marker of the real frequency with the maximum amplitude, falling into this range. Lights up in yellow. The position of the optimum frequency marker can be changed. So, after starting the program or after clearing all the notes, the position of this marker is determined by the ideal frequency of the equal temperament scale at the frequency of the **A4** base note. After obtaining the optimal solution or after loading a saved scale from a file, the position of this marker may not coincide with the ideal one.

In this fragment, you can scale and shift vertically or horizontally using standard gestures.

The right side of the 3rd fragment is used to display information about the first five harmonics. Here you can select a harmonic by moving the frame up and down. Each line displays the calculated (optimal) frequency of the selected harmonic, it is highlighted in bright green. Then the real frequency and the difference between them in cents.

Virtual keyboard

Used to select a note. Standard gestures allow left-right shifts and scaling: all or part of the keyboard by three octaves. When you enter a note in auto detect mode, the note on the keyboard is set automatically. In the virtual keyboard, the current note is marked with a red rectangle, recorded notes – with green rectangles and notes included in the temperament zone – with blue rectangles. For example, A2, .., A3,…, A4,…, A5.

HFS configuration description
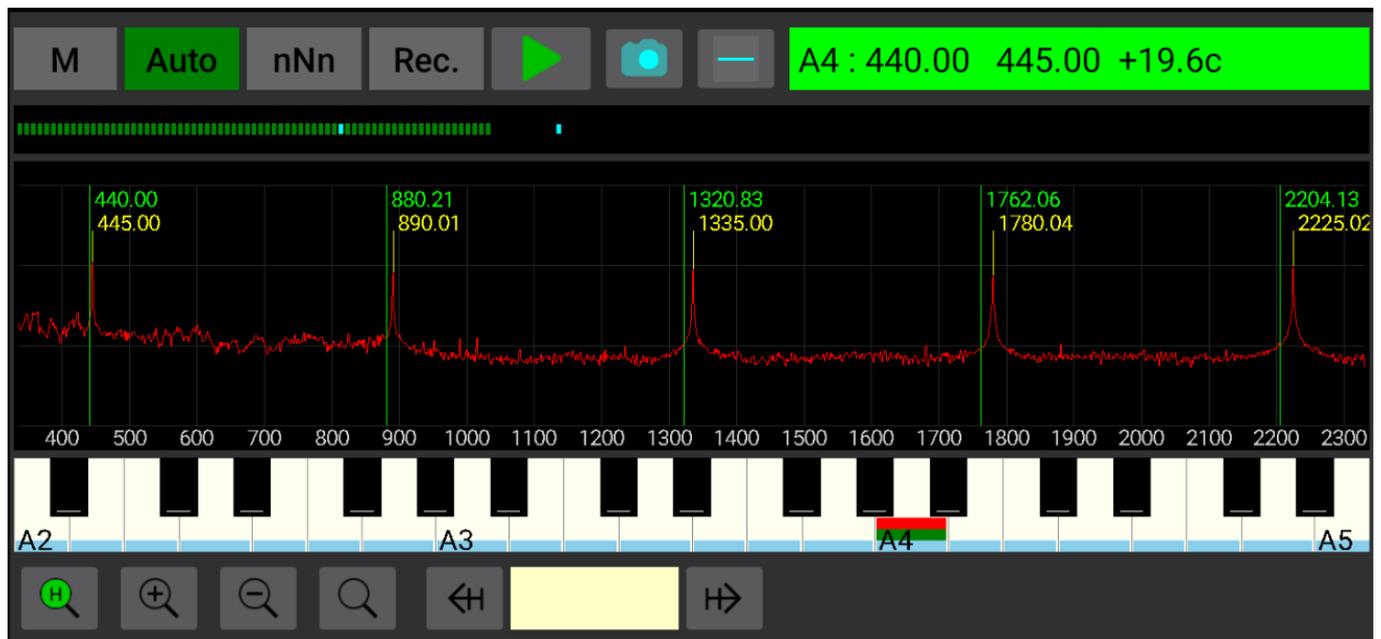
The window is divided vertically into 6 fragments:

- Two rows of buttons: at the top and bottom of the screen.

- Input level.

- Frequency marker panel.

- Spectrum panel.

- Virtual keyboard.

Top row of buttons, input level and virtual keyboard are similar to H configuration.

Spectrum panel

It has two scales: along the Y axis – a scale of amplitudes in dB. and the X-axis is a linear frequency scale in Hz. and the spectrum itself. As in the **H** configuration, optimal and real markers are displayed here, but unlike **H**, you can consider the entire spectrum from the 0th frequency to the frequency determined by the FFT / 2 block value. In this fragment, you can scale and shift vertically or horizontally using standard gestures.

Bottom row of buttons

- Button ⊕ - scaling the spectrum horizontally, in which all 5 harmonics are placed in the spectrum panel.

- Button ⊕ - horizontal enlargement of the spectrum.

- Button 🔍 - horizontal scaling of the spectrum.

- Button 🔍 - reset the spectrum scale horizontally and vertically.

- Buttons ⟨H, H⟩ - moving along harmonics with a change in scale.

Pop-up menu

Same for all configurations. Called by pressing the M button in the top row of buttons:

- **Settings** – call the window for changing the program settings. Here you can configure some parameters of the input signal processing and spectrum visualization. The default parameters are sufficient for setting the average accuracy. In this case, the accuracy of determining the frequencies of the notes will be approximately equal to 0.08 Hz. (0.4 cents for the middle of the range) or 1 beat in 10 seconds.

- **Switching configurations.**

- **Save file.**

- **Open file.**

- **Inharmony**.

- **Intervals**.

- **Railsback**.

- **Finding the optimal solution.** Starting the module for calculating the optimal frequencies for the temperament zone.

- **Resetting the current note –** returns the parameters of the current note to their original state. Useful when you enter a note incorrectly.

- **Reset All Notes** – Initializes the entire scale according to the principle of equal temperament, ie. the frequencies of adjacent notes decrease or increase to the 12th root of 2. The note A1 is taken as the base note

- **Reset cutoff line.**

- **Peak holding.**

- **Signal generator.**

- **Registration** – information on the program status, serial number and activation button.

- **Exit the program.**
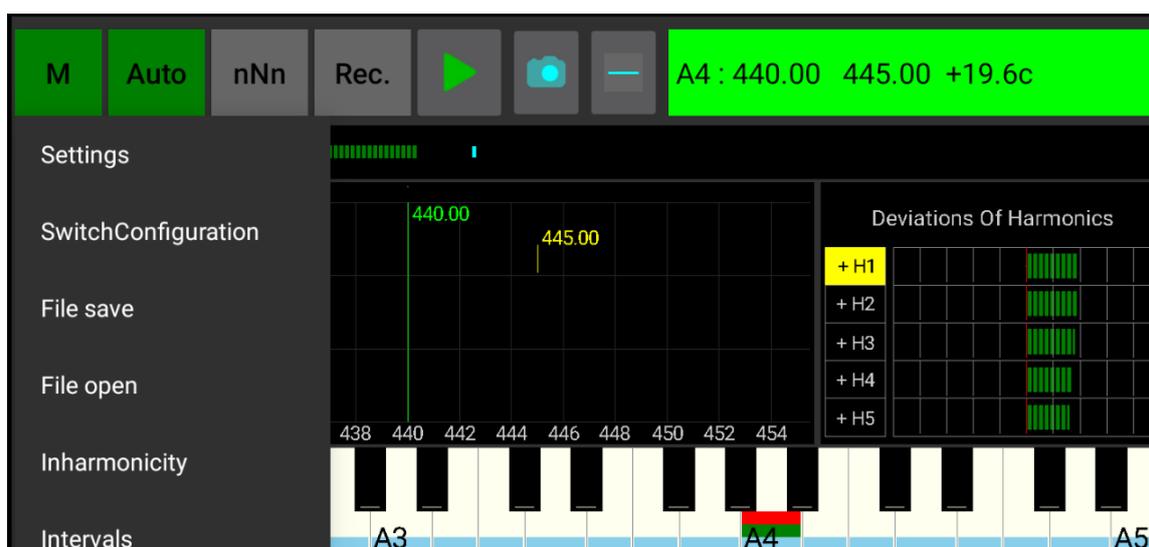
The scheme of the program

The entire piano scale from **A0** to **C8** is stored in program memory. When the program starts, the scale is initialized by the base note **A4**. The calculated harmonic markers for each note are highlighted at these initialized values.

In short, the markers for calculated and real harmonics are:

- Marker of the calculated (optimal) harmonic – a vertical line on the spectrum graph with a coordinate along the frequency axis equal to the frequency of the calculated harmonic.

- Real harmonic marker – a vertical line on the spectrum graph with a coordinate along the frequency axis equal to the real harmonic frequency.

Note. For more information on markers, see **Appendix 2**.

When the button ▶(**Start)** is pressed, the process of inputting a sound signal from an input device (usually a microphone) is started. The received signal is converted in the program using the fast Fourier transform algorithm into a spectrum and displayed on the screen in real time. When the audio signal exceeds the **MAXs** level, the spectrum analysis begins for the presence of harmonics of a note from the acceptable range.

If any **valid** note is found in the spectrum, then the maxima of the amplitudes of the harmonics of the recognized note are stored in a temporary table. According to them, the window of harmonics values is filled and **markers of real harmonics** (yellow verticals) are highlighted and the current note is automatically switched to the recognized one. The color of the note name in the spectrum window turns bright green.

Spectrum analysis is performed until the audio signal level is below the **MINs** level.

If recording was allowed, then in the "**Auto**" mode, among the saved states of notes in the temporary table, the note with the maximum sum of the weighted amplitudes of the harmonics is selected, which is written into the program memory. **In manual mode**, after the note is recognized, the decision to record is made by the tuner himself by pressing the "**Stop**" button. For the recorded note, the information in the **harmonic values window** is saved. If there was no record, then this information is discarded.

It is convenient to control the process of entering a note by individual harmonics in the window of harmonics values. You can also analyze harmonics in the spectrum window by selecting the scale - "**H**" (all harmonics, for **HFS** configuration) or by any one harmonic.

In the tuning mode (recording is prohibited), according to the markers of real and calculated harmonics, you can make a decision – to pull up or to loosen the string. Since the spectrum is updated quite often, a change in the string tension is quickly reflected in the spectrum. As soon as the real marker is brought to the optimal one (combined), you can move on to the next note.

Real harmonic markers appear when a note is recognized. However, when tuning a specific string, it is not at all necessary to wait until the note is recognized and the real markers appear. It is enough for a more or less formed peak of the 1st or 2nd harmonic to appear and set the string so that these peaks are closer to the optimal (calculated) marker.

The frequencies of the **initialized scale** may not correspond to the frequencies of the scale of a real equal-tempered instrument, since they do not take into account the specifics of the instrument, the inharmony of specific strings, the features of the soundboard, etc.), but this ideal tuning can be used as a first approximation or preliminary lifting of the strings. This is a variant of using the program as a chromatic tuner.

If there is no need to lift the strings beforehand, then the temperament zone is first tuned, then the bass and treble are tuned according to the tuned zone.

To set up a temperament zone, you need to record all the notes of the zone (one string per chorus) and run the module for calculating the optimal plan. If an optimal plan exists, then the **markers of the calculated (optimal) harmonics** for each note

of the temperament zone are highlighted already according to these found values, and it remains only to display the **markers of the real harmonics** of each note of the zone on these **calculated (optimal) markers**.

The tuning of the notes of the bass and treble is carried out as standard according to the already tuned notes of the temperament zone. It can be helpful to use a **snapshot of the spectrum** of the corresponding note in the temperament zone.

The work results can be saved in a file. A qualitative picture of the tuning of the entire scale or part of it can be obtained using some types of intervals in the corresponding windows.

The main stages of working with the program

- starting the program;
- setting the main parameters of the program;
- preliminary tuning of the scale, if necessary;
- tuning the temperament zone;
- tuning the rest of the scale.

If you intend to use an external microphone, then it must be connected **before starting** the program.

Launching the program
The use of the program is oriented towards the landscape position of the device. Turns are not performed after starting the program!

Setting basic parameters
At the initial stage of mastering the program, it is recommended to use the default parameters. Change the program settings if necessary. For details on setting see **Appendix 3.**

After starting the program, we get to the main window:

Click the button ▶(**Start)** (if not pressed yet) and check the spectrum display of the input signal. The spectrum should change over time and respond to the microphone.

Press the A4 key on the piano. The screen should look something like the picture and should respond to the microphone.

Piano presetting (if necessary)

The frequencies of the **initialized scale** may not correspond to the frequencies of the scale of a real equal-tempered instrument, since they do not take into account the specifics of the instrument (inharmonious of specific strings, features of the soundboard, etc.), but this ideal tuning can be used as a first approximation.

If the scale of the instrument rises in several approaches, gradually reaching the desired pitch, then this is achieved in the program by changing the frequency of the base note **A4** in the settings, which leads to the initialization of the scale at the set frequency. And it is enough just to raise the scale in accordance with the initialized row, without achieving special accuracy and without writing notes into the program memory.

So, to perform **piano presetting**, you need to set the required base note frequency. Start the input process, i.e. push the button ▶(**Start)**, select a note and adjust the yellow **marker** (**or just the peak**) of the first or second **real harmonic** of the selected note to the green marker of the first (second) **optimal harmonic**. Without stopping the input process, go to another note and repeat the adjustment of the markers (peaks). And so – for all notes.

If fine tuning is required, the temperament zone is first adjusted, then the bass and treble are adjusted according to the tuned zone.

Tuning the Temperament Zone(TZ)

1 We check the frequency of the base note A4 in the menu / settings, usually this frequency is 440 Hz. If you need a different frequency, then change it and exit the settings by "OK".

2 Then you need to enter all the notes of **TZ**, by default, this is the range from **A2** to **A5** inclusive. Note input during recording should only be done for one string in the chorus. That is, all but one of the strings in the choir must be muted. It is convenient to use a felt tape of
sufficient length to cover the entire **TZ**. Button "**Record"** must be pressed.

3 After recording all the notes, we check if any note is out of harmony from the general row. To do this, select the "Inharmony" option from the menu.
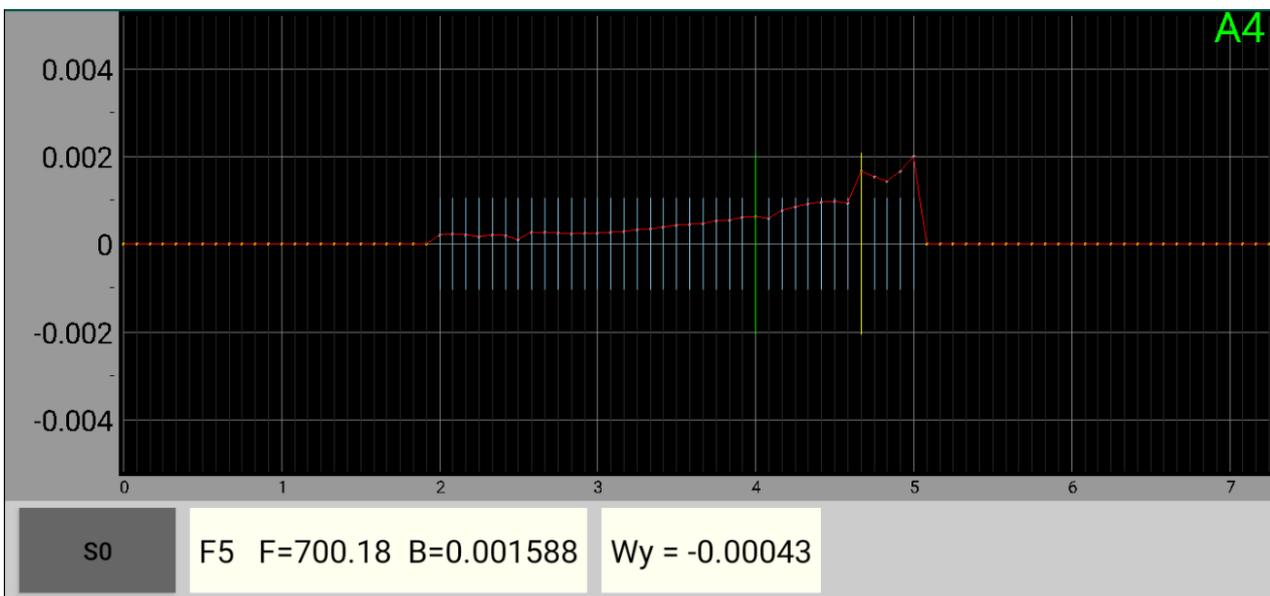
The figure shows that the note **F5** is slightly increased in harmony. Let's re-enter this note just in case. In my case, this did not help: apparently, it is such a string or the shape of a hammer. But it is still recommended to do this procedure.

4 After entering all the **TZ** notes, we start the process of finding a solution – the option "Finding the optimal solution" in the pop-up menu. If there is a solution, the markers of the optimal harmonics for the notes of the temperament zone will correspond to the found tuning plan.

5 Save to file and turn off recording: button color [Rec.] will turn gray [Rec.].

6   Next, we tune the strings in the **TZ** choirs. First, one string in the chorus, bringing it to the **optimal marker**, then the remaining strings in the chorus in unison with the first tuned. For greater accuracy, it is better to tune notes not according to the first harmonic, but according to the second or higher.

Note. The solution is sought so that the beats in quarts, fifths, thirds and sixths fall within a certain interval. The width of this interval is minimized, and the difference between the 2nd harmonic **A2** and the 1st harmonic **A5** would be minimal. The solution may not exist under all constraints. If a solution exists, then a pop-up information window displays a message stating that the solution has been found with an indication of the ratio of the sum of deviations of real frequencies from ideal and deviations of the found solution for all 4 intervals.

The solution may not exist in the case when one or several notes differ significantly in frequency from the values of the initialized scale.

Comparison of spectra. Tuning unison. Tuning the rest of the scale

The tuning of the notes of the bass and treble is carried out in "octaves" according to the already tuned notes of the temperament zone. You can use the Spectrum **Snapshot** of the corresponding note in the temperament zone. Trigger **Button**

Spectrum Snapshot used to fix the current spectrum on the screen. This captured spectrum can be used for comparison with subsequent spectra.
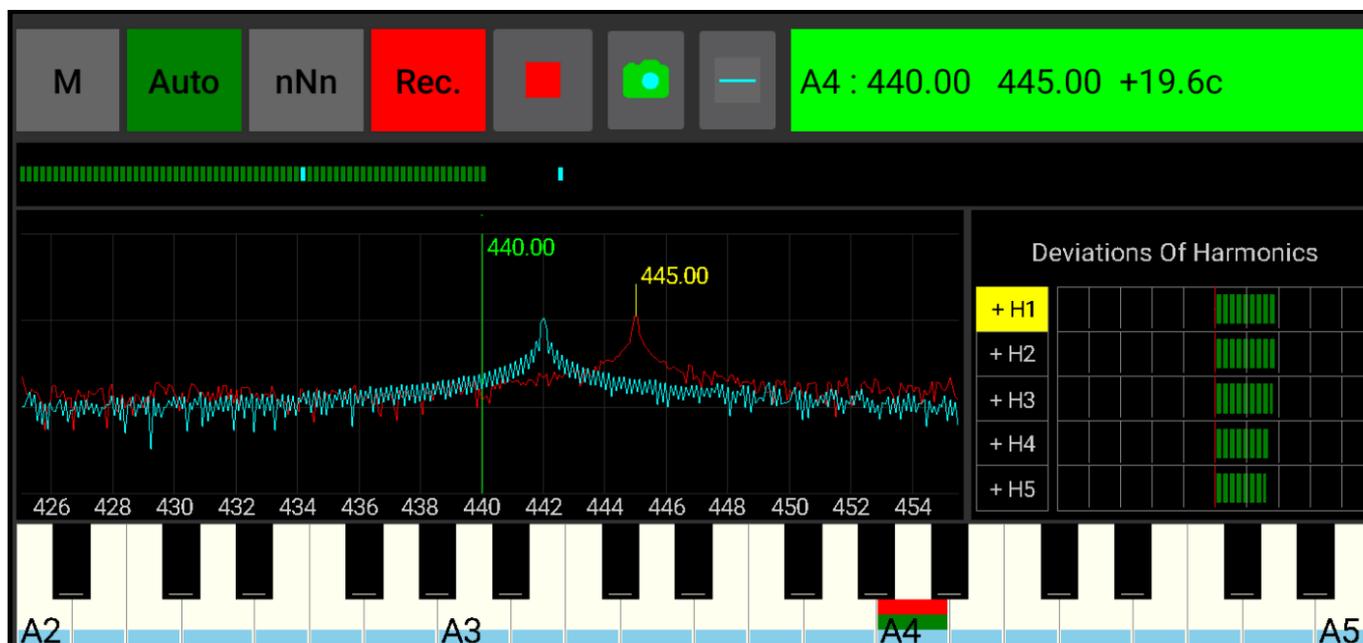
Pressing the **Spectrum Snapshot** button again resets the **Snapshot**.

The figure shows two spectra: the blue spectrum – the snapshot and the red spectrum – the current spectrum.

Spectrum comparison can also be used to tune unison.

So, to tune the rest of the scale, you need to go through all the notes of the temperament zone in turn. Take a **Snapshot** for each note and tune the corresponding note from the adjacent octave in unison. This, of course, does not cancel auditory control. The fact is that the inharmonicity of the strings can manifest itself in different ways and it is not always possible to equalize all the coinciding harmonics of the interval. In such cases, you have to compromise and choose a more euphonious option by ear. This is especially noticeable when tuning bass.

Features of entering notes when recording

A note on the microphone. Budget microphones, as a rule, do not take frequencies below 100 hertz, that is, approximately, frequencies below the frequency of the 1st harmonic of the **A2** note. There is also a limitation on the high frequencies. But this is not really necessary, since you can work with the program for bass using the 2nd and higher harmonics. And for the tops we take the lower harmonics. It is only important that the microphone confidently picks up the frequencies of the notes from the temperament zone (**TZ**), since we must write the frequencies of these notes into the program and then get the optimal solution for the **TZ**. During subsequent tuning, it is not necessary to record notes outside the temperament zone (it is enough to observe the spectrum or in the harmonics window).

Writing notes to the computer's memory is allowed only when the "**Record**" mode is enabled

Features of Input in Auto Mode

In this mode, the search for a valid note is carried out along the spectrum of the entire scale of the piano. The analysis starts when the input signal level exceeds a certain threshold value (the right blue bar in the input signal level window – **MAXs** marker). The analysis ends when the signal level falls below a certain minimum (the left blue bar in the input signal level window – **MINs** marker).

Thus, the input level should be higher than **MAXs** when the piano key is first pressed, and lower than **MINs** in silence mode.

The position of the **MAXs** marker in the signal level window can be changed by grabbing and moving left / right. This is sometimes useful when increasing the strength of a key strike or changing the signal level in the system settings does not have an effect.

In a noisy room, to reduce the likelihood of false triggering when detecting a note in the "**Auto**" mode, you can search for notes only among adjacent notes in relation to the current one – one

 note to the left or right. To do this, you need to turn on the button . The background color of this button turns green. For example, if the current note is **A4**, then you can only enter the notes **G#4**, **A4**, and **A#4**. You cannot enter other notes. This is also useful when entering notes around the edges of the **TZ**.

At the end of the analysis, the best one is selected among the recognized notes and its recording is allowed. **Writing a note to the program memory in the "Auto" mode is performed automatically after the analysis of the note is completed.**

Features of manual input

If the "**Auto**" button is off, that is, the manual mode is set, the search for a note in the spectrum is limited only to the part of the spectrum of the current note. The note recognition process begins almost immediately after the current signal level exceeds **MINs**. But only if the current note coincides with the one recognized in the input signal, the note is considered valid and its recording is allowed. The background of the information panel with the name of the note turns bright green. From now on, you can record the note.

Recording is performed by pressing the (Stop) button. The moment of pressing is determined by the tuner himself.
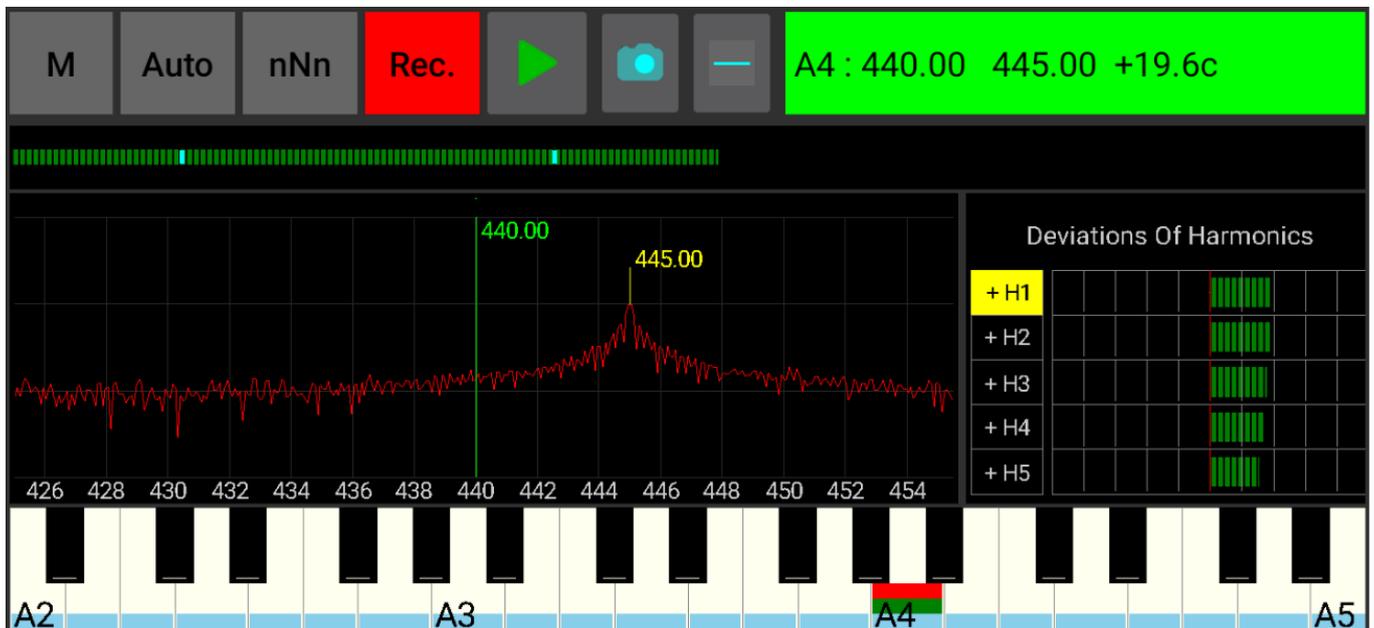
The figure shows that in the manual mode, the note **A4** was introduced with the frequency of the 1st harmonic ~ 445 Hz. This note was recognized (the background of the panel with the note name is bright green) before the input signal level exceeded corresponding to the position of the right **MAXs** marker in the input signal level window. And the pressing of the "**Stop**" button was made before the input signal level dropped below the level of the left **MINs** marker.

If the note is stored normally, a short beep will sound. You can check which notes have been saved in the subwindow of the virtual keyboard.

## Noise cutoff line limitations(COL)

When entering a signal for recording, it is **important** that all harmonics have an amplitude above the cutoff line of the noise level – the blue line in the spectrum window. If any of the five harmonics "lie lower" - the note will not be recognized. Therefore, if the note is not recognized, then it is necessary to check whether all harmonics are above the **COL**.

Turning on / off the display of **COL** is done by pressing the button (the background of the button in the pressed state is green). When the **COL** display is on, it is possible to correct small areas of the **COL** by pressing and then moving. The shift up or down of the entire **COL** is done by short pressing in the right or left half of the spectrum, respectively. Resetting the **COL** is carried out by the menu option **"Reset cutoff line".** Turning on the **COL** display **blocks the spectrum scaling or shifts.**

What to do if the pressed note is not recognized

Check:

- In Auto mode, the input level is exceeded at the moment the piano key is pressed to the **MAXs** level. If increasing the strength of the key strike or changing the signal level in the system settings has no effect, then you can change the position of the **MAXs** marker in the signal level window by **grabbing and moving this marker left-right**.
- Note input completion occurs when the input level falls below **MINs**. If in silence mode, the signal level exceeds **MINs**, then you should reduce it in the system settings.
- Check if all harmonics in the spectrum lie above the cutoff line (**COL**). In the right pane of the harmonics table (for configuration H), a plus or minus sign is displayed in each row on the left, depending on whether this harmonic lies above or below the **COL**. If any of the harmonics lies below, change the type of **COL** for this harmonic so that the peak of the harmonic is above the **COL**.
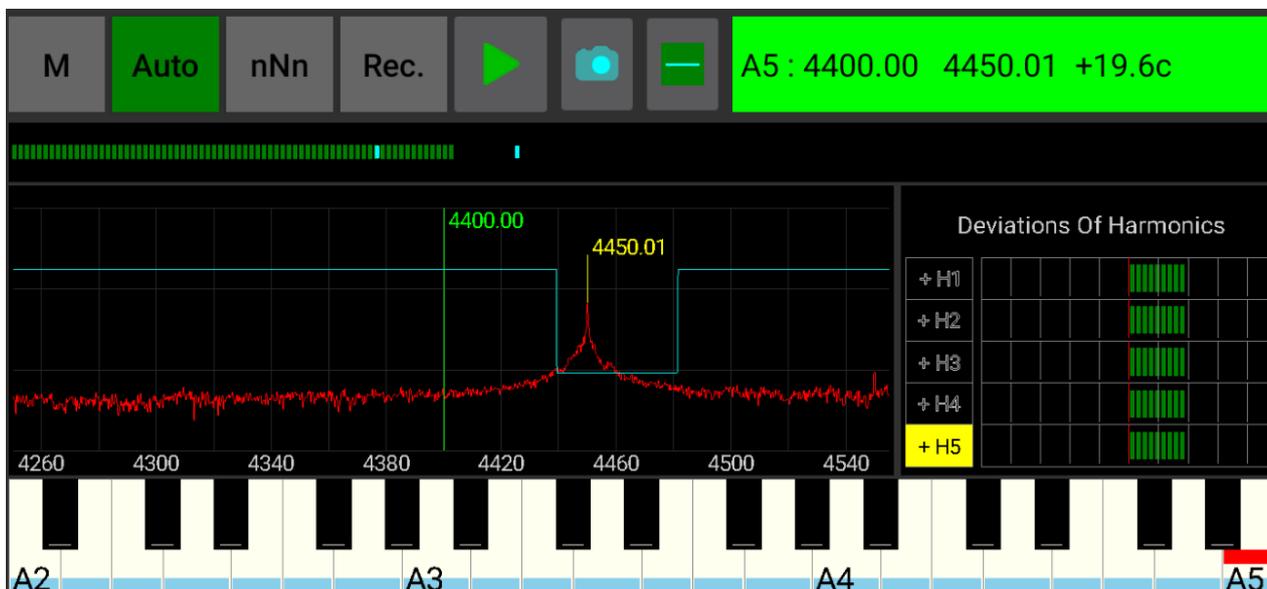
The figure shows the **COL** correction for the 5th harmonic of the **A5** note. Since the amplitude of the 5th harmonic practically coincides with the **COL**, for a stable recognition of this note, the **COL** fragment was somewhat lowered in this place.

Sometimes it is convenient to use the Peak Hold menu option for spectrum analysis. Then, after we have dealt with the problematic harmonics, "Peak Hold" should be turned off.

- If you cannot enter a certain note in "**Auto**" mode, you can try entering it manually. In manual mode, note recognition does not need to exceed the **MAXs** level — it is sufficient for the level to exceed the **MINs** value. But in this case, the note is recorded by pressing the "**Stop**" button.
- It is also recommended, after completing the entry of notes of the temperament zone, to check in the disharmony window (called from the menu) if any of the notes is too out of the general row. Then you need to repeat the input and recording of this note.

Resetting notes

If you find that some note has been entered incorrectly, then it can be reset (initialized) by setting this note from the program keyboard and choosing the menu option "**Reset current note**".
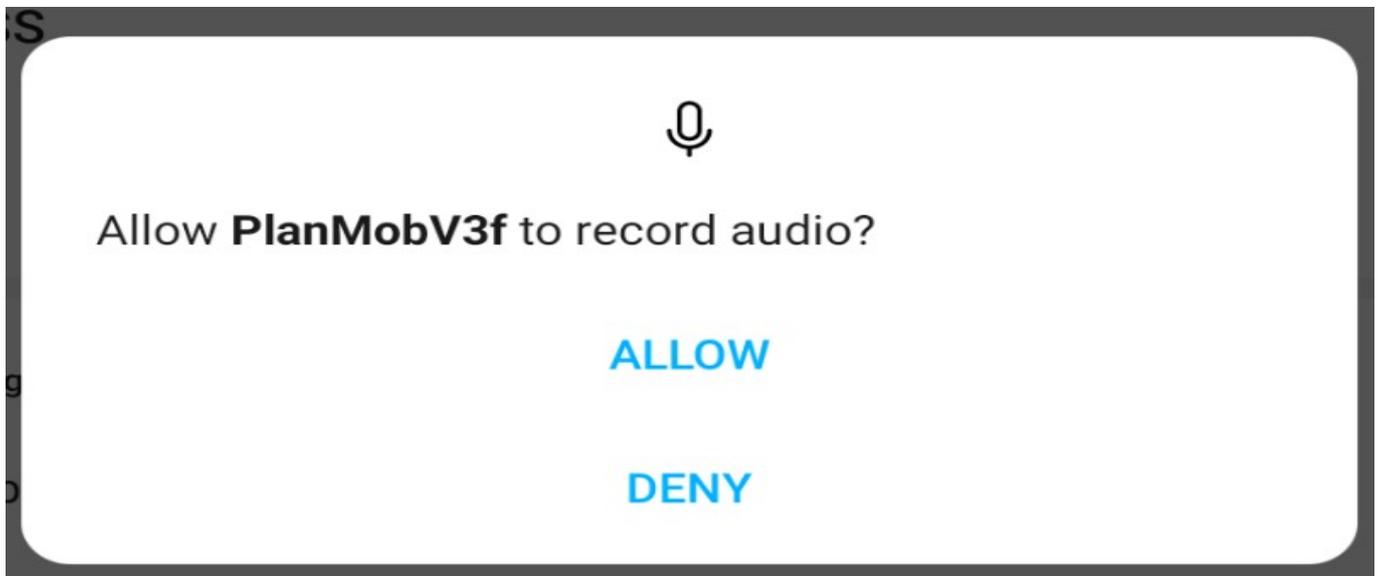
Reset (initialization of the entire scale) - via the "**Reset all notes**" menu. This action requires confirmation, since if the answer is yes, **all the information entered will be lost**.
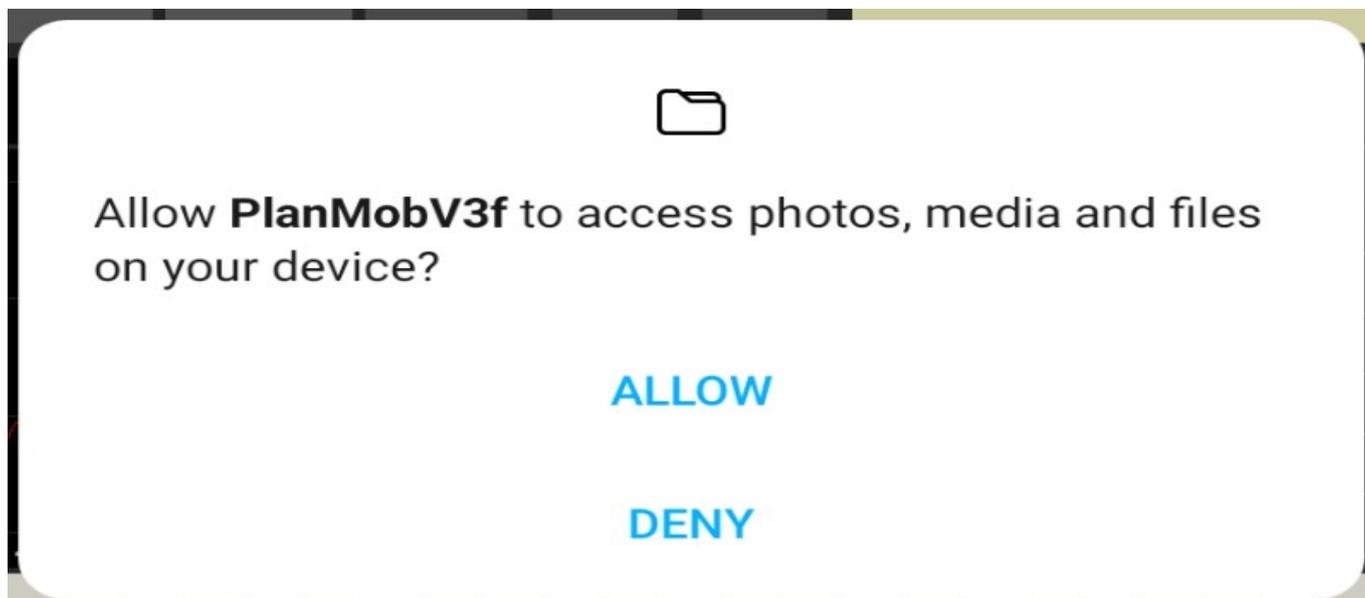
Appendix 1. Installation warnings
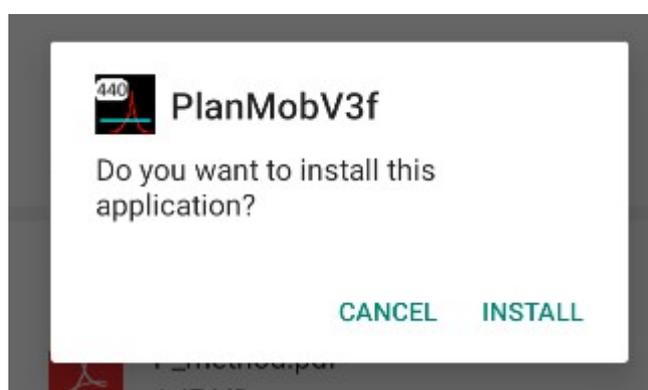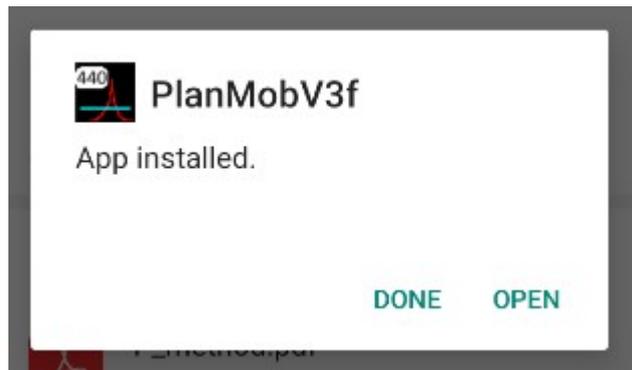
We agree in all these cases. After installing and starting the program, more warnings for audio recording may appear:

and working with files:

Here we also allow recording and working with files.

Appendix 2. Some concepts

Sampling rate (Fs) - sampling rate of a continuous signal in time when it is digitized. The higher the **sampling rate**, the wider the spectrum of the input signal can be represented in the discrete signal. For example, with a sampling rate of 22050 Hz, the spectrum is represented from 0 to 22050/2 Hz. The sampling rate in PianoLabM can be set to 8000, 16000, 11025, 22050 and 44100 Hz.

Fast Fourier Transform (FFT). Algorithm for transferring a signal from the "time-amplitude" area to the "frequency-amplitude" area.

FFT analysis block size (FFTsize). This parameter determines the number of spectral lines per period generated by the **FFT** algorithm - i.e. the accuracy of the **spectrogram**.

Spectral resolution (Sres) - frequency resolution of each spectral line. It is equal to **Fs / FFTsize**. For example, if **FFTsize** is 128k (131072) and **Fs** is 22050 Hz, then **Sres** is 22050/131072 = 0.17 Hz. Obviously, increasing the **FFTsize** increases **Sres**, but also increases the time required to perform computations.

Time Resolution – defines the length of one period per second. **FFT** algorithm for given **Fs** and **FFTsize**. Time resolution is the reciprocal of the spectral resolution. For example, if the **FFTsize** is 128k and the sampling rate is 22050 Hz, then the temporal resolution is 5.94 sec.

Thus, **spectral** and **temporal** resolution is inversely proportional, i.e. an improvement in one parameter leads to a deterioration in another. To improve interactivity, the audio pickup is buffered. This allows the spectrogram to be updated more frequently than once per **time resolution** period.

The scale of the piano – the notes of the scale in the program are numbered from 0 to 87, and the octaves – from 0 to 7. Thus, the notes of the scale in Russian notation change from **A0** to **C8**.

The interval coefficient is the ratio of the frequencies of the semitone. In equal temperament, this is a constant, independent of the place in the scale, and is equal to the 12th root of 2, approximately 1.05946. Since the number of semitones in an octave is 12, the ratio of frequencies in an octave is exactly 1: 2.

The base note is the **A4** note. In the scale of the program it has number 48. It is assumed that the frequency **A4** is 440 Hz. When you start the program, the scale values are initialized exactly at the base note frequency in accordance with the principle of equal temperament.

Temperament zone(TZ) – in the program, this is the sequential (continuous) part of the piano scale that is tuned first. For an ideal instrument, the ratio of adjacent equal temperament frequencies is equal to the **interval ratio**. In this case, beats in fourths / fifths, thirds / sixths obey certain patterns. For a real instrument, the determining factor in tuning the zone is not the ratio of adjacent frequencies, but the preservation of the behavior of these beats.

Scale initialization – a program mode in which all frequencies of the scale are assigned calculated values based on the **base note A4** and the interval coefficient without taking into account the inharmonicity of the strings, i.e. the first harmonics of the scale (fundamental tones) are calculated by multiplying or dividing the frequency of the **base note** by the **interval factor**, and the remaining harmonics are taken as multiples of the fundamental tone.

Railsback curve – a curve that determines the magnitude and nature of the deviations of the frequencies of the scale of a particular instrument from the frequencies of the scale of the "ideal" instrument (calculated mathematically), where each subsequent semitone differs from the previous one by multiplying or dividing by the **interval coefficient** and **harmonics** are considered ideal. The **X**-axis of the Railsback curve is where notes are placed, and the **Y**-axis is the deviation in cents. In the absence of deviations, the Reilsback curve takes the form of a horizontal straight line.

The optimal tuning plan is a set of all notes of the **temperament zone** (with their own harmonics), calculated by the program according to certain criteria for a particular musical instrument.

The beat frequency is the absolute value of the difference in the frequencies of the added vibrations.

A **cent** is one hundredth of a semitone. The cent is a logarithmic unit: for example, one cent in the **A4** region is approximately 0.26 Hz, and in the **A3** region it is already 0.13 Hz.

Cutoff line is generated automatically in the program and is used to separate the useful signal from noise. Immediately after starting the program or after resetting this line, it looks like a straight line. It is possible to locally change the cutoff line in order to exclude certain parts of the spectrum from the analysis of the note.

Harmonics

One of the basic concepts in the program is the concept of **harmonics**.

Harmonic – any complex oscillation can be represented as a sum of the simplest sinusoidal oscillations with strictly defined frequencies, amplitudes and phases (Fourier transform). These simplest vibrations are called natural frequencies. An overtone is any natural frequency above the first, lowest (**fundamental**), and those overtones whose frequencies refer to the frequency of the fundamental as **integer numbers** are called **harmonics**, and the fundamental is considered the first **harmonic**. Since, in a real instrument, the values of harmonic frequencies may differ from the theoretical ones, we will distinguish between theoretical (ideal), real and calculated harmonics:

- **An ideal harmonic** is a harmonic, the frequency of which is obtained by multiplying or dividing the frequency of the base note by the **interval coefficient**.
- **Real harmonic** – the harmonic of the note recorded in the program from the microphone when you press a real piano key. It is sought in the spectrum as a local maximum in the vicinity of the theoretical harmonic for a given note. The frequency of the real harmonic before recording coincides with the ideal.
- **Calculated (optimal) harmonic** – a harmonic, the frequency of which is calculated in the program according to certain rules, taking into account the inharmonicity of the strings.

The importance of the concept of **harmonics** in the program is explained by the fact that the sound signal of a pressed piano key, which is just a complex oscillation, is converted into the sum of the simplest sinusoidal oscillations, i.e. signal spectrum. Then harmonics are highlighted in the spectrum, which are used to recognize the note.

Calculated and real harmonics markers

- **The marker of the calculated (optimal) harmonic** is a vertical line on the spectrum graph with a coordinate along the frequency axis equal to the frequency of the **calculated harmonic**. The default is bright green.
- **The real harmonic marker** is a vertical line on the spectrum graph with a coordinate along the frequency axis equal to the **real harmonic** frequency. It is highlighted in yellow by default.

For all **calculated harmonics** of the current note, **markers of calculated harmonics** are highlighted in the spectrum window. At the initial stage – before starting the module for finding the optimal solution, the markers of the **calculated harmonics** exactly coincide with the frequencies of the initialized scale, that is, with the values of the ideal harmonics. **Then the position of these markers can change depending on the results of the search for the optimal solution.**

The markers of the calculated harmonics are always highlighted, and the **markers of the real harmonics** only if the note is recognized and recognized as acceptable, in the sense that there are harmonics in the spectrum that fall in the vicinity of the ideal harmonics of the current note and the amplitudes of all harmonics **lie above the cut-off line**. If the note is recognized, the information panel with the name of the note turns bright green and only in this case it is allowed to write the note to the computer memory.

Appendix 3. Description of program settings

To change the settings, press the M menu button, then Settings and select what we need to adjust:

- Frequency of the base note **A4**;

- Parameters that determine the accuracy of calculations: sampling rate and **FFT** size;

- Boundaries of the temperament zone;

- Fixation of the English interface language;

- The checkbox for visualizing the spectrum amplitude scale in **dB**;

The default parameters are recommended for the initial stage of using (mastering) the program, as they provide an acceptable balance between the quality of the input signal processing and the requirements for the computer's processor power.

1   The base note frequency **A4 –** by default is equal to **440Hz**.
2   Sampling frequency. By default – **11025**, which corresponds to the maximum frequency of the analyzed signal – 5400 Hz (Note Do3 with 5th harmonics). If you need to tune higher notes, you need to increase the sampling rate. The selection of the sampling rate in the program is limited to the standard values – 8000, 11025, 16000, 22050 and 44100.

3   **FFT** analysis block size. The default is **131072** (128k). With a sampling rate of 11025 and an analysis unit size of **FFT** = 128k, the spectral resolution is **0.08 Hz**. This roughly corresponds to one beat in 11 seconds. If this accuracy is not enough, then it can be increased by either decreasing the sampling rate or increasing the **FFT** block size.