

Classroom acoustics – analysis, simulation and optimization

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Abstract: Noise is an everyday stress factor in classrooms, a fact that is confirmed by teachers in numerous studies. In this contribution, three tools are presented, which are useful for analyzing, simulating and optimizing room acoustics in classrooms. These tools were developed as project thesis at the Graz University of Technology with the aim for further investigations of the noise situation in classrooms. The application *IntKlaSim* is a further development of an already existing tool. On the one hand, it analyzes a classroom's acoustics after a reverberation time measurement was performed. On the other hand, an acoustical restoration of this room can be simulated by selecting different absorbers from a data base, which are put in the room additionally. The attention of analysis and simulation is directed to reverberation time, STI and AI_{cons} . In addition, the File Cutter and the Noise Level Analyzer are two new realized applications. These tools can be used to evaluate the noise environment at different positions in classrooms simultaneously and in dependency of the selected style of teaching. Thereby, the innovation of the last two applications is the possibility to analyze a multichannel recording of class. Hence, it is possible to evaluate parameters, like the background noise, not only at one certain position, but in dependency of room acoustical conditions spatially distributed.

Key words: analysis, simulation and optimization of classroom acoustics, noise evaluation

1. INTRODUCTION

Noise in school is a problem that occurs daily. But only since a couple of years it is dealt with seriously in Austria. In the search for reasons for the moderate Austrian result at the PISA test, the topic "Noise in school" was brought into focus. A study, performed in 2007 and 2008, delivered the result that the noise level in classrooms is much too loud and that education is affected by noise. Among other results the study also revealed that noise has negative influence on the teacher's well-being [1].

At approximately the same time, the topics "Noise in school" and "Classroom acoustics" came to the fore at the Signal Processing and Speech Communication Laboratory of the Graz University of Technology. In September 2009, a literature research concerning this topic was accomplished with the diploma thesis of Maurice Müller titled *Klassenraumakustik (Classroom acoustics)* [2]. This thesis investigates the effects of noise and reverberation time on pupils and teachers in a classroom. In the beginning, it looks into the acoustical conditions in a classroom. Furthermore, it is proved that a connection between room acoustics and noise level exists. After several different measurements at schools were evaluated, it was

demonstrated that it is possible to classify the acoustics of a classroom according to the year of construction and that the acoustical requirements specified in the norm DIN 18041 [3] are not complied in most of the cases.

The next step at the Graz University of Technology happened with the diploma thesis of Claudia Reithner, titled *Akustische Sanierung von Klassenräumen (Acoustical restoration of classrooms)* [4]. In the context of this thesis, a guideline was developed that introduces physics teachers in the performance of an acoustical restoration that can be done within the scope of project work for example. In addition, a first version of the tool *IntKlaSim* that can be used to simulate an acoustical restoration was released. This tool was written with Microsoft Excel.

Referring to this thesis, the verification of the guideline's road capability followed with the bachelor thesis of Michael Flohrschütz [5]. In addition, the tool *IntKlaSim* was extended by a broad data base of absorbers in order to make the simulation of more different improvements possible.

The tools that are presented in this contribution are tied in with this history. As already mentioned, these tools were developed as project thesis at the Graz University of Technology. This thesis is titled *Entwicklung von*

Werkzeugen zur Untersuchung der Klassenraumakustik im Unterrichtsbetrieb (Development of tools for classroom acoustics investigation during class) [6].

On the one hand, the tool *IntKlaSim* was enlarged with several possibilities. For example, the feasibilities of simulation for STI and Al_{cons} were extended by including the classroom's background noise in the simulation.

On the other hand, two new analysis tools were developed with regard to further investigations of the noise situation in classrooms. These new applications are called *File Cutter* and *Noise Level Analyzer*. Both are Matlab applications. With these applications it is possible to investigate the noise environment at different positions in the classroom simultaneously, while the analysis is performed according to the selected style of teaching. Therefore, it is necessary to record a day or a lesson at school with several microphones distributed in the classroom. Subsequently, the *File Cutter* categorizes the single tracks according to the styles of teachings. After categorization is finished, the *File Cutter* copies all parts that belong to the same style of teaching in a separate wave file. These files are loaded into the *Noise Level Analyzer*, where the evaluation takes place.

To perform such investigations concerning the noise level in classrooms, a conventional sound level meter can be used as well. However, a sound level meter only measures the sound field at one certain position in the room. Because these tools offer the possibility to analyze a multi-channel recording, the sound field can be evaluated at multiple positions in the room simultaneously. Thus, local sound field differences can be detected and it can be analyzed at which places in the classroom the noise exposure for pupils and teacher is extreme. By categorizing the recording according to the style of teaching before the analysis, an investigation that inspects the influence of different styles of teachings on the noise distribution in the classroom can be operated.

These tools will be applied in a master's thesis. This thesis will include experiments that investigate the background noise in classrooms and the dependency of the teacher's voice level on the background noise. These investigations can be performed at the BRG Kepler in Graz excellently, because about one half of the classrooms were sanified acoustically in the summer holidays 2014. The remaining classrooms are in the same acoustical state as in the year of construction at the beginning of the 20th century. Under these conditions, the investigation of the background noise and the teacher's voice level in good and bad acoustical environments can be analyzed very well. During these experiments, the parameters can be analyzed under spatial surveillance and can be connected with the acoustic situation in the room. Meanwhile, the spatial spreading of the values can be observed, too.

In the following, the functionality and possibilities of the introduced tools will be presented.

2. ROOM ACOUSTICAL SIMULATIONS USING THE TOOL *IntKlaSim*

The tool *IntKlaSim* - abbreviated version for *Interdisziplinäres Klassenraumakustik Simulationstool (Interdisciplinary classroom acoustics simulation tool)* - is an application for the analysis of the present acoustical situation after a reverberation time measurement was performed and for the simulation of a room acoustical optimization. For the reverberation time measurement, the software *ARTA* (<http://www.artalabs.hr/>) is recommended, because it is cheap software with multiple functions and the import of reverberation time measurements in *IntKlaSim* is optimized for measurements made with *ARTA*. The focus of this application is put on reverberation time, STI and Al_{cons} . Previous versions of this tool were already released by Claudia Reithner and Michael Flohrschütz. For further information on the previous versions, please refer to [4] and [5]. The proceeding steps for a simulation and the possibilities of this tool are presented in the following.

After starting the tool, the spread sheet *Intro*, is displayed. This sheet offers a brief explanation of the possibilities of the application.

The first values have to be entered on the next tab, called *Basisdaten* (*Basic data*):

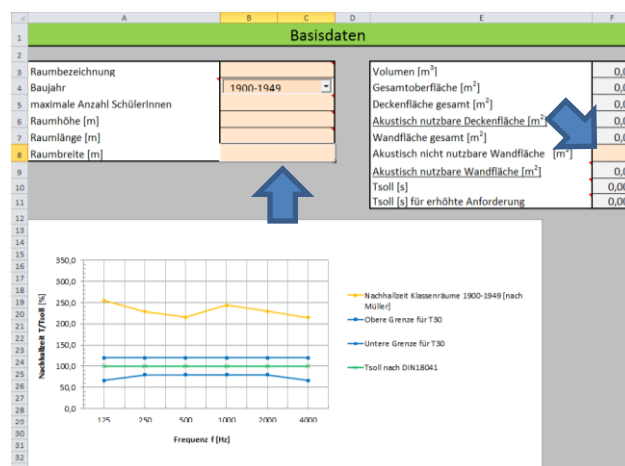


Fig. 1. *IntKlaSim* – Basic data

The data to be entered are the room's appellation, the year of construction, the maximum number of pupils, the height, length and width of the room and the wall area that is not usable for an acoustical restoration, like blackboard or windows. These values have to be entered in the cells that have an ochre background color. The room volume and different surface dimensions are calculated from these entries. From the room volume, the tool calculates the optimal reverberation time as well as the reverberation time for raised requirements defined in the norm DIN 18041 [3]. With selecting the year of construction, a frequency depending reverberation time curve that is typical for the year of construction is displayed in the chart below. These values are the results of the measurements of Müller [2] and are only rough approximations.

[illegible]

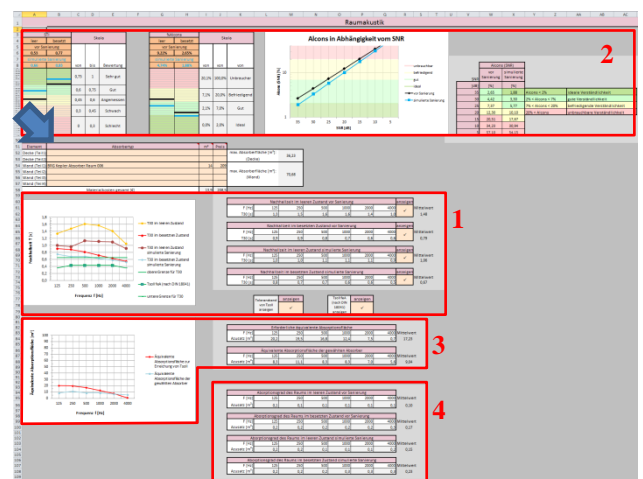
At the beginning, the state of occupation of the room during the reverberation time measurement must be prompted in line 3. (I. e. was the room empty during the measurement or was the measurement performed while the pupils were present.) After that, the data of the reverberation time measurement must be imported to the tool. As already said, the data import is optimized for measurements performed with ARTA. With ARTA, the measurement results can be saved as a csv-file via *Analysis* → *ISO3382 – acoustical parameters* → *Table presentation for 1/1 octave bands*. This file can be selected and loaded via pushbutton *Messwerte importieren (Import data)* in cell A5. If the measurement was not made with ARTA, the data has to be available in the following format as csv-file so that the automatic measurement import is possible:

	A	B
1	F (Hz),T30 (s)	
2	63,1.00	
3	125,1.00	
4	250,1.00	
5	500,1.00	
6	1000,1.00	
7	2000,1.00	
8	4000,1.00	
9	8000,1.00	
10		

Several files can be selected simultaneously. The values for STI male, STI female and AI_{cons} have to be entered separately and can be found in *Analysis* \rightarrow *STI*. For a detailed user guide concerning room acoustical measurements with ARTA please refer to [4]. If wrong data was imported, the respective measurement can be removed via selecting the respective data in column E and pushing the button *Messwerte entfernen (Remove data)* in cell A6.

Import der Messwerte vor Sanierung										
Raum vor Sanierung			Raum		Raum		Raum		Raum	
Messwerte Eingangsform			Messwerte		Messwerte		Messwerte		Messwerte	
Messwerte eingangsform	umfa	ts	ts	ts	ts	ts	ts	ts	ts	ts
Messwerte eingangsform	umfa	ts	ts	ts	ts	ts	ts	ts	ts	ts
Raum000_1_M1	0.5191	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312
Raum000_1_M2	0.5039	0.9378	0.9378	0.9378	0.9378	0.9378	0.9378	0.9378	0.9378	0.9378
Raum000_1_M3	0.5203	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312	0.9312
Raum000_1_M4	0.5351	0.9401	0.9401	0.9401	0.9401	0.9401	0.9401	0.9401	0.9401	0.9401
Raum000_1_M5	0.5078	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120
Raum000_1_M6	0.5170	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120	0.9120
Raum000_1_M7	0.5264	0.9300	0.9300	0.9300	0.9300	0.9300	0.9300	0.9300	0.9300	0.9300
Raum000_1_M8	0.5255	0.9408	0.9408	0.9408	0.9408	0.9408	0.9408	0.9408	0.9408	0.9408
Raum000_1_M9	0.5394	0.9455	0.9455	0.9455	0.9455	0.9455	0.9455	0.9455	0.9455	0.9455
Raum000_1_M10	0.5351	0.9309	0.9309	0.9309	0.9309	0.9309	0.9309	0.9309	0.9309	0.9309
Raum000_1_M11	0.5294	0.9304	0.9304	0.9304	0.9304	0.9304	0.9304	0.9304	0.9304	0.9304
Raum000_1_M12	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M13	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M14	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M15	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M16	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M17	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M18	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M19	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M20	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M21	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M22	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M23	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M24	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M25	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M26	0.5351	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308	0.9308
Raum000_1_M27	0.5351	0.9308	0.9308	0.9308						

On the following tab *Raumakustik* (*Room acoustics*) (see Fig. 5), the room acoustical simulation can be started.



In the beginning, absorbers for ceiling and wall must be selected from the dropdown-menu in the cells from B52 to B57. Detailed technical information about the respective absorber can be found on the sheets *Absorberliste Decke* (*List of absorbers ceiling*) and *Absorberliste Wand* (*List of absorbers wall*). These sheets might be hidden. The favored absorber size can be typed in the cells from I52 to I57. If the greatest possible absorber size that is calculated via the room dimensions is exceeded, the font color changes to red and a lower value must be entered to continue.

Below this table, the absorbers' influence on the room's reverberation time is illustrated (see Fig. 5 mark 1). Individual curves can be hidden via deleting the check mark next to the respective data table. To blend the curve again, an arbitrary entry must be entered into the respective cell. Above the table of absorbers, the impact of the absorbers to STI and AI_{cons} is demonstrated (see Fig. 5 mark 2).

Furthermore, the AI_{cons} in dependency of the SNR is illustrated. In this graph, the values at 10 dB and 15 dB are of particular importance because these are typical values for the ratio between the teacher's voice level and the pupils' background noise in a classroom. Below the reverberation time graph, the equivalent absorption area of the chosen absorbers and necessary equivalent absorption area to reach the optimal reverberation time are shown (see Fig. 5 mark 3). For the sake of completeness, the absorption factors of the respective state of occupation with and without absorbers are appended at the end of this tab (see Fig. 5 mark 4).

The next sheet *Lärmsituation und Sprechaufwand* (Noise environment and voice level) (see Fig. 6) continues with the simulation of the real life working situation in the room by considering the present number of pupils and the room's background noise.

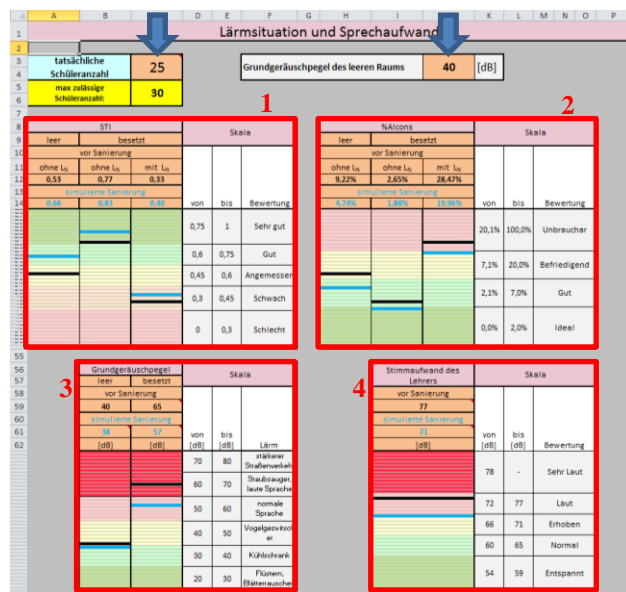


Fig. 6. *IntKlaSim* – Noise environment and voice level

At first, the present number of pupils must be typed in cell C3 and the background noise measured in the empty room must be fed into cell J3. These data are used to calculate the background noise with present pupils before the restoration and the background noise considering the absorbers. The influence of these noise levels on the STI and the AI_{cons} is demonstrated in the two graphs below (see Fig. 6 mark 1 and 2). At the end of the tab, the different background noise levels are compared with each other (see Fig. 6 mark 3) and the background noise's influence on the teacher's voice level is illustrated (see Fig. 6 mark 4). Studies showed that the power of the teacher's voice is about 11 dB higher than the background noise produced by the present pupils [7].

After a real restoration of the room has been completed, and a reverberation time measurement in this state was performed, the results of the real restoration can be compared with the simulated ones and the state before restoration. Therefore, it is necessary to import the new data into the tool in a similar manner as the data of the measure-

ment before the restoration. This happens on the sheet *Import der Messwerte n(ach) S(anierung)* (Measurement import after restoration) (see Fig. 7).

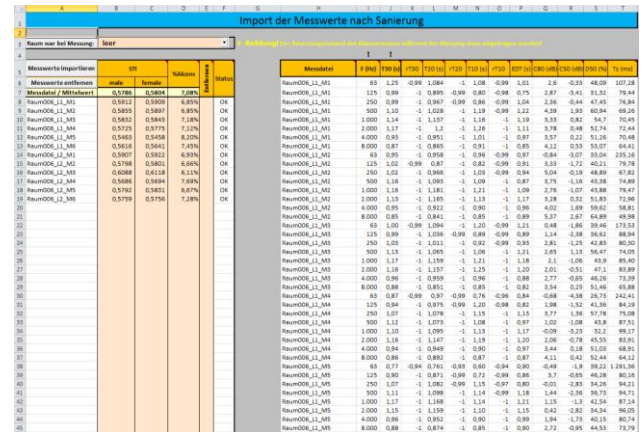


Fig. 7. *IntKlaSim* – Measurement import after restoration

On the last tab, *Vorher-nachher-Vergleich* (Before and after comparison) the respective variation of reverberation time, STI and AI_{cons} are compared with each other (See Fig. 8). Whether the results of the performed restoration are compared with the simulations for the empty room or with pupils present is depending on the state of occupation that was selected for the measurement after the restoration.

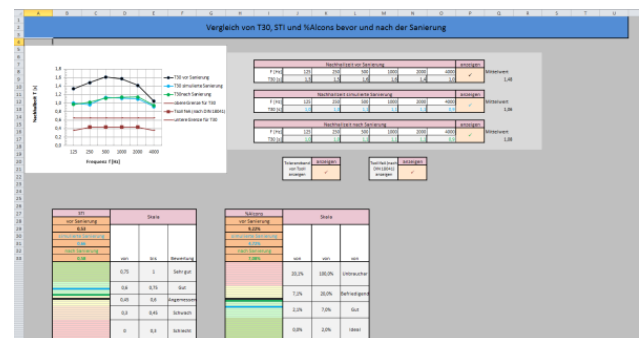


Fig. 8. *IntKlaSim* – Before and after comparison

To sum up, it can be said that the tool *IntKlaSim* offers the possibility to simulate an acoustical restoration by checking the influence of additional absorbers on reverberation time, STI and AI_{cons} . Moreover, the sheet *Noise environment and voice level* demonstrates the connection between room acoustics and communication acoustics. Thereby, the influence of the present number of pupils on the background noise and the dependency of the background noise on the teacher's voice level are shown. Several investigations that deal with communication acoustics in classrooms have already been made. But most of these data are antiquated and do not respect the room acoustics. In order to investigate the connection between room acoustics and communication acoustics in a master's thesis and to receive solid and authentic data, two applications, called *File Cutter* and *Noise Level Ana-*

lyzer, were realized that can be used to analyze such phenomena spatially distributed. These applications will be introduced in the following chapter.

3. NOISE EVALUATION IN CLASSROOMS

3.1 Approach during the analysis

This chapter describes the steps that need to be performed when the noise environment in a classroom is investigated with the *File Cutter* and the *Noise Level Analyzer*. Before the main analysis can be started, it is necessary to record a day or a lesson at school with several microphones distributed in the classroom. Conventional recording equipment is sufficient. Regarding the microphone selection, omni-directional microphones should be selected. Before the recording can be started, the microphones need to be calibrated. It is necessary that the calibration signals are also recorded, because the *Noise Level Analyzer* needs a reference signal for the calculation of the sound pressure level. Now the main recording can be started. During class, a list needs to be prepared that contains the times with the respective chosen styles of teachings (for example: Only teacher is talking or team work is employed). After class is finished, the single tracks must be exported as a wave file. Thereby, it is required to create an extra track that contains the calibration signal for each single track. Hereupon, the tracks are loaded to the first Matlab tool, the *File Cutter*, where the categorization according to the respective style of teaching takes place. After categorization is finished, the *File Cutter* copies all the parts that belong to the same style of teaching in a separate wave file. These files, together with the respective calibration file, are loaded into the second Matlab tool, the *Noise Level Analyzer*, which is responsible for the noise analysis.

A manual for the *File Cutter* delivers the next chapter and the manual for the *Noise Level Analyzer* contains chapter 3.3.

3.2 The File Cutter

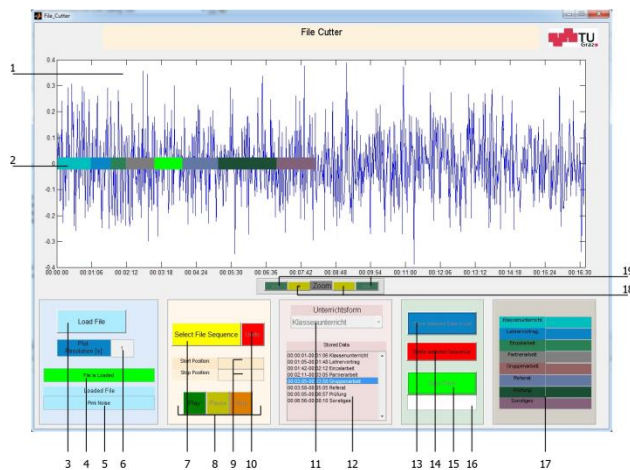


Fig. 9. Overview of the *File Cutter*

1	Plot Window	Displays the file's time dependent course and the selected sequences.
2	Markers	Indicate the selected sections color-specifically according to the style of teaching.
3	Button <i>Load File</i>	At the touch of this button, the file to be categorized can be loaded.
4	Information window 1	Gives feedback about the loading status.
5	Information window 2	Shows the name of the loaded file.
6	Information window <i>Plot Resolution</i>	Time resolution of the plotted visualization; default one sample per second is displayed.
7	Button <i>Select File Sequence</i>	At the touch of this button, an arbitrary sequence can be selected in (1).
8	Audio Player	Plays the section that is selected in (7) or chosen in (12).
9	Information window 3	Shows start and stop position of the file sequence selected in (7).
10	Button <i>Undo</i>	Deletes the section that was selected with (7).
11	Popup menu <i>Unterrichtsform</i>	Assigns the section that was selected with (7) to a style of teaching.
12	Table <i>Stored Data</i>	Shows the stored and categorized sections.
13	Button <i>Store Selected Data in List</i>	Stores the sequence in (12), which was selected with (7) regarding the style of teaching, selected in (11).
14	Button <i>Delete selected Sequence</i>	Deletes a stored sequence that is chosen in (12).
15	Button <i>Save Files</i>	Saves the categorized sequences in dependency of the assigned styles of teachings in separate wave files.
16	Information window 4	Gives feedback about the saving status.
17	Information window 5	Shows the duration of the saved files.
18	Buttons <i>Zoom In / Zoom Out</i>	Magnifies or diminishes the plot in (1).
19	Buttons <i>Scroll left / Scroll right</i>	Scrolls the plot in (1) to the left or to the right if the zoom is activated with (18).

Table 1. Controls of the *File Cutter*

File loading:

After launching the tool, the file that is to be edited must be loaded. This happens via pushbutton *Load File* (3). The favored file has to be stored in the same folder as the

Matlab file of the *File Cutter*. Also, the file must be in wave format. Files in other formats cannot be edited with this tool. After loading is completed successfully, the hint “*File is Loaded*” is displayed in information window 1 (4). In addition, the file name is displayed in information window 2 (5). As the class recordings are large files, the loading process may last for a longer period. When the file is loaded, a data reduced wave form is plotted in the Plot Window (1). Only the first sample for each second is plotted there. This is necessary since, if no data reduction would be made here, the following selection of file sequences would be too computationally intense. The current design was selected, because the signal’s wave form remains visible despite the data reduction by the factor of the sampling frequency. For that reason, the following sequence selection is accurate to the second. But this is not a problem, regarding the length of the files. The plotted number of samples per second is also displayed in information window *Plot Resolution* (6).

Sequence selection:

Via pushbutton *Select File Sequence* (7), the start and end position of a file section can be marked. After the button was pushed, a cross line appears with which the selection can be performed by selecting the desired pixel in the Plot Window (1). It is irrelevant whether start or stop position is marked first. The mark with the lower time specification is chosen automatically as the start position. After that, the selected sequence is marked red. The selected section can be played via the Audio Player (8). If a wrong section was marked, it can be deleted via pushing the button *Undo* (10).

Categorizing a sequence:

The selected sequence has to be categorized and stored now. To categorize the section, a style of teaching must be selected in the popup menu *Unterrichtsform* (11). Via pushbutton *Store Selected Data in List* (13), the sequence is stored according to the selected style of teaching in the table *Stored Data* (12). The selected section is now color-specifically marked in the Plot Window (1). The color specification depends on the selected style of teaching. Now a new selection can be started. The stored sections can be played via the Audio Player (8) as well. Therefore, it is necessary to select the desired section in the table *Stored Data* (12). If a wrong section was stored, it can be deleted via selecting the respective one in the table *Stored Data* (12) and pushing the button *Delete selected Sequence* (14) in the following.

Exporting the stored sections:

After categorization is finished, the parts that belong to the same style of teaching are exported in separate wave files. This happens via pushbutton *Save Files* (15). Information window 4 (16) informs about the progress. When all files are created, the lengths of the created files are shown in information window 5 (17). If several sequences were categorized according to the same style of teaching, the tool copies all the parts one after another in chronological order in one file. The files are stored in the same

folder as the original file. They have the same name as the original file with the style of teaching appended (for example “*filename Klassenunterricht*”). In addition, a text file is generated that contains the sequences’ start and stop positions as well as the assigned style of teaching. This file is named “*filename Dokumentation*”. In the end, a Matlab file is generated that contains - among other things - the variables that contain the sections’ start and stop positions and the assigned styles of teachings. This file is named “*filename Background Data*”. While a file is loaded in the beginning, the tool always checks if such a Matlab file already exists. Therewith, it is possible to interrupt the categorization and continue at another time after the button *Save Files* (15) has been pushed.

Categorization of a multichannel recording:

When another track of the same class recording is to be categorized, it is not necessary to repeat the whole procedure. It is sufficient to copy the Matlab file containing the background data into the folder with the respective track and name it according to the new track to be analyzed (for example: “*filename_2 Background Data*”). Then, the Matlab file is loaded simultaneously with the new file and transfers the start and end positions of the sequences selected in the previous categorization to the new file. Thus, only the button *Save Files* (15) has to be pushed to export the categorized wave files of the new recording. Of course, a modification is possible before the file export is started.

3.3 The Noise Level Analyzer

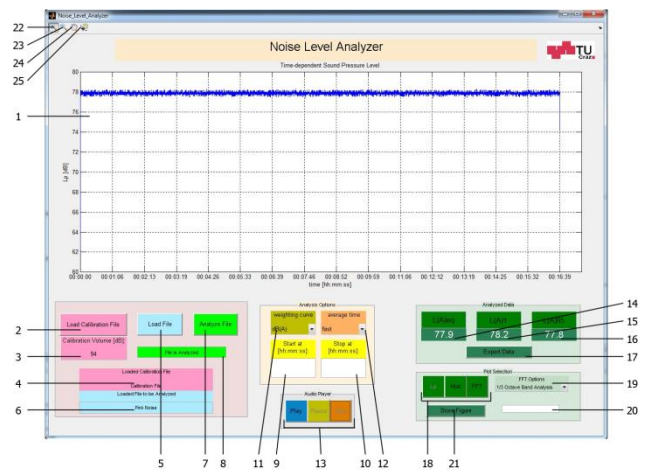


Fig. 10. Overview of the *Noise Level Analyzer*

1	Plot Window	Displays the time dependent sound pressure level, its histogram or the FFT.
2	Button <i>Load Calibration File</i>	Loads the file that contains the calibration signal.
3	Input window <i>Calibration Volume</i>	Input window for the calibrator’s reference volume (default: 94 dB).

4	Information window 1	Shows the name of the calibration file.
5	Button <i>Load File</i>	At the touch of this button, the file to be analyzed can be loaded.
6	Information window 2	Shows the name of the file to be analyzed.
7	Button <i>Analyze File</i>	At the touch of this button, the time dependent sound pressure level is calculated. For feasible options see (9), (10), (11), (12).
8	Information window 3	Gives feedback about the loading and analysis status.
9	Button <i>start at</i>	Optionally, a start time for the analysis can be entered here (default: 00:00:00).
10	Button <i>stop at</i>	Optionally, a stop time for the analysis can be entered here (default: end of the file).
11	Popup menu <i>weighting curve</i>	Selection of a frequency curve (default: dB(A))
12	Popup menu <i>Average time</i>	Selection of a time averaging constant (default: fast)
13	Audio Player	Plays the analyzed file.
14	Output window <i>Leq</i>	The energy equivalent continuous sound pressure level is displayed here.
15	Output window <i>L1</i>	The sound pressure level that is exceeded in 1% of the measurement time is displayed here.
16	Output window <i>L95</i>	The sound pressure level that is exceeded in 95% of the measurement time is displayed here.
17	Button <i>Export Data</i>	Exports the data determined during the analysis to a text file.
18	Buttons <i>Lp, Hist, FFT</i>	The visualization of the sound pressure level, its histogram or the FFT of the analyzed file can be selected here.
19	Popup menu <i>FFT Options</i>	If the FFT was chosen in (18), it can be distinguished between an octave band analysis, a third octave band analysis and a twelfth octave band analysis.
20	Information window 4	Shows the progress of the computation selected in (18).
21	Button <i>Store Figure</i>	Saves the current GUI surface as jpeg file.
22	Zoom in	Magnifies the visualization in (1).
23	Zoom out	Diminishes the visualization in (1).
24	Pan	Pans the visualization in (1) to the left, to the right, up and down.
25	Data Cursor	X and Y coordinate of a pixel, selected in (1), are displayed.

Table 2. Controls of the *Noise Level Analyzer*

Loading a calibration file:

At the beginning, the file that contains the signal of the calibrator must be loaded. With this signal, the reference sound pressure level is calculated, which is essential for the calculation of the time dependent sound pressure level. The reference volume of the used calibrator has to be entered in the input window *Calibration Volume* (3). Subsequently, the calibration file can be loaded with pushbutton *Load Calibration File* (2). As already mentioned, this file must be located in the same folder as the Matlab file of the *Noise Level Analyzer*. After loading is finished, the information window 3 (8) displays “*Calibration File is Loaded*” and information window 1 (4) contains the calibration file’s name.

Loading a file categorized by the File Cutter:

The file to be analyzed can be loaded via pushbutton *Load File* (5). When loading is completed, the file name is displayed in information window 2 (6).

File Analysis:

The analysis of the loaded file can be started with pushbutton *Analyze File* (7). Before the analysis is started, several options can be switched. The options can be found in the box *Analysis Options*. Different frequency weightings (dB(A), dB(B), dB(C) and flat) (11) and time average constants (fast, slow and impulse) (12) are available for selection. Moreover, it is possible to select only a section of the loaded file for the analysis. The optional start and stop time can be entered in (9) and (10). If no changes are made in this box, the file is analyzed with the default settings that can be found in Table 2. After analysis is finished, the hint “*File is Analyzed*” is displayed in information window 3 (8) and the Plot Window (1) shows the time dependent sound pressure level. Moreover, the L_{eq} , the $L_{1.0}$ and the $L_{95.0}$ can be read off from the Output windows (14), (15) and (16).

The analyzed file can be played by the Audio Player (13). The playback respects the chosen frequency curve.

The histogram of the sound pressure level or a spectral analysis of the file can be calculated by pushing the button *Hist* or *FFT* in the *Plot Selection* (18). If the FFT was selected, the user can distinguish between an octave band, a third octave band or a twelfth-octave band analysis by selecting the favored resolution in the popup menu *FFT Options* (19).

A new analysis respecting other analysis options can be started after each finished analysis.

Saving the analysis results:

After the analysis is finished, the whole level statistics, containing the L_{eq} , $L_{0.1}$, $L_{1.0}$, $L_{10.0}$, $L_{33.3}$, $L_{50.0}$, $L_{66.6}$, $L_{90.0}$, $L_{95.0}$, $L_{99.0}$ and $L_{99.9}$ can be exported as a text file by pressing the button *Export Data* (17). This text file is named “*filename Dokumentation*”. If several analysis of the same file were made, the current statistics is appended to end of the file containing the data from previous analysis.

The current GUI surface can be saved as a jpeg file at a touch of the button *Store Figure* (21). To avoid overwrit-

ing when several different analysis of the same file were made, the name of this file contains the selected plot and the analysis options (for example: “filename Klassenunterricht Lp dB(A) fast 00 00 00 – 00 06 26”).

4. CONCLUSION

In this contribution, tools that realize a versatile and accurate investigation of classroom acoustics and the noise environment in classrooms were presented. The tool *IntKlaSim* offers the possibility to analyze the present acoustic situation in a classroom after a reverberation time measurement was performed. After that, it is possible to simulate an acoustical restoration of this classroom. By respecting the background noise and the present number of pupils, it is possible to investigate the real working situation in the classroom and to connect room acoustics with communication acoustics. Thereby, the influence of the absorbers on the background noise and the background noise’s influence on the STI, the AI_{cons} and the teacher’s voice level are simulated. In the end, a real restoration can be compared critically with the simulated results and the situation before the restoration.

With the *File Cutter* and the *Noise Level Analyzer*, two new applications were created that allow the evaluation of the noise environment during class. With the *File Cutter*, it is possible to separate a multichannel recording of class according to the selected styles of teachings. Thus, with the *Noise Level Analyzer*, the investigation of the noise environment can be performed in dependency of the selected style of teaching. The wide level statistics that is calculated by the *Noise Level Analyzer* offers the possibility to make detailed conclusions about the noise environment. By calculating the histogram of the time dependent sound pressure level, a statistical analysis can be performed as well.

As already mentioned, an investigation concerning the analysis of a noise environment can be passed with a sound pressure level meter, too. However, the sound level meter measures the sound field only at one certain position. Because of the possibility to evaluate a multichannel recording, the user can investigate the spatial distribution and spreading of these parameters. Thereby, conventional recording equipment is sufficient.

Of course, the application area of these tools is not limited to classroom acoustics. The application *IntKlaSim* can be used for any room, in which the reverberation time, the STI and the AI_{cons} are to be analyzed and optimized. According to this, the *Noise Level Analyzer* can be used to evaluate the noise environment in any favored room.

In a master’s thesis, these tools will be applied in order to investigate the effects of room acoustics on communication acoustics. Investigations that evaluate the teacher’s daily noise exposure level $L_{EX,8h}$ shall be performed, too. In these investigations, it shall be found out how the $L_{EX,8h}$ depends on the room acoustics and by how much the $L_{EX,8h}$ is decreased by shorter reverberation times.

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