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Final Dissertation

BACHELOR'S DEGREE IN COMPUTER SCIENCE

A WEB GRAPHICAL USER INTERFACE FOR THE PACKET-LOSS-CONCEALMENT TESTBENCH TOOL

Student	Supervisor	Co-Supervisor
Stefano Dallona	Prof. Luca Turchet	Ing. Luca Vignati

Good morning/afternoon to everyone, I would like to thank all the committee members for attending the discussion of my thesis work.
My name is Stefano Dallona and I'm a student of the Bachelor's Degree in Computer Science. I am, and I've been for the entire course of my studies, a full time student worker. The title of my thesis is "A Web Graphical User Interface for the Packet-Loss-Concealment Testbench Tool."
When I first got in touch with professor Turchet and I was proposed a thesis work complementary to a Ph.D research in the file of Digital Audio processing, I accepted It enthusiastically. In my job I had never had the opportunity to deal with software related to entertainment, so the topic was totally new to me and challenging.

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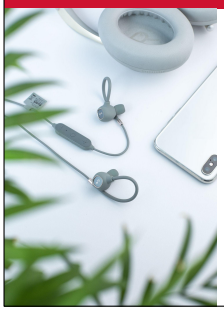
Introduction



1. **Context**
   PLC Testbench, a tool for the comparison of Packet Loss Concealing algorithms
2. **Problem**
   Interaction difficult due to the lack of a graphical user interface available
3. **Solution**
   Development of a graphical user interface

As I mentioned, my thesis was strictly connected to the Ph.D work from Luca Vignati, who developed a software framework for the evaluation of PLC algorithms.
PLC algorithms try to minimize the disturbance caused by packet loss in an audio stream by reconstructing the lost portions of the audio signal according to different strategies. The topic has become more and more relevant as nowadays, users of audio services provided on the Internet, expect high quality even when connected to the Web via wireless connections while being on the move. In this scenario obviously, packet losses are very likely to happen.
Before my thesis work the only type of interaction with the user natively supported by the testbench tool was by direct code modification and execution inside an Integrated Develpment Environment like Visual Studio Code. On top of this, the output information from the program was not integrated and therefore the analysis was a bit cumbersome and inefficient.
The development of a Graphical User Interfacce was seen as a solution to these problems.
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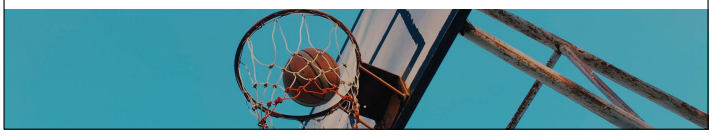
Purpose of the Thesis

Develop a **Graphical User Interface for the PLC Testbench** tool
in order to support

QUANTITATIVE and **QUALITATIVE**
comparison of PLC algorithms



In particolar the objective of the PLC Testbench is enabling the qualitative and quantitative comparison of different PLC algorithms and the purpose of the GUI was to make the interaction with the tool ad Easy, efficient and pleasant as possibile.
Qualitative evaluation of the algorithms mainly consists of waveform, spectrograms visual comparison and listening to original and reconstructed audio file portions.
Quantitative comparison is essentally based in the data container in the metrics calculated by the program on each audio file.

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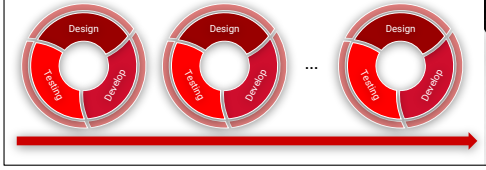
Methodology

Iterative development process
to
- **shorten release cycles / fast feedback**
- **minimize risk of useless development**



From a metodological perspective, since at the very beginning of the work I knew very little about the subject and most of the coordination between me and Vignati had necessarily to happen remotely, it looked wise to setup weekl or bi-weekly checkpoints to validate the work done. An ITERATIVE agile development process based on the Kanban method was adopted because of its simplicity and flexibility. More strucrured processes like Scrum seemed to be and overkill in this situation. The process was essentally based on short cycles of design/develop and testing phases which brought big benefits, like keeping the focus on small clear objectives and getting fast feedbak on the developed functions, this minimizing the risk of wasting time in developing useless use cases.

Technologies

React
frontend
widgets

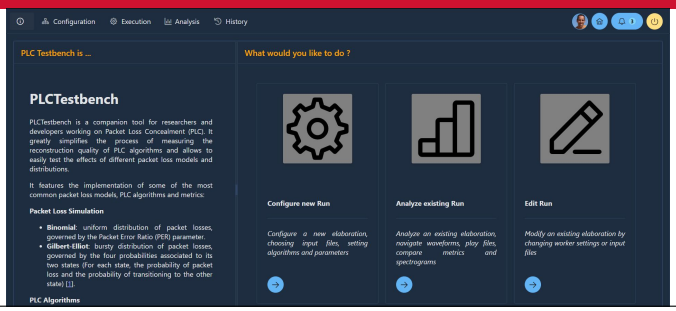
Flask
backend
RESTful API

Docker
packaging &
containerization

Circle CI
build & deploy

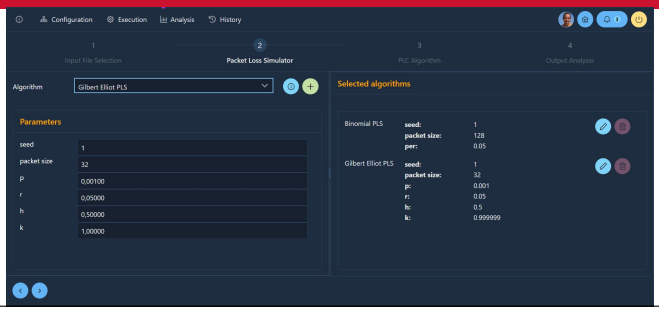
In the inital design phases a major choice had to be made on the type of GUI to be developed. Pros and cons of the different options were carefully weighted up and in the end the decision was made to go for a Web GUI, because of its ease of distribution, scalability and accessibility.
A PLC Testbench frontend based on a web application could be deployed in a variery of modes ranging from a standalone instance on a single machine to highly scalable distributed infrastructures.
From an archtectural point of view the web application was split into 2 layers: a frontend developed in JavaScript and based on React framework, and a backend, developed in Python with the help of the Flask framework.
Bundling and distribution was addressed by containerizing the application as a Docker image, while for build and deploy I leveraged the pipelines as code solution offerte by Circle CI Cloud platform.

GUI - Landing Page



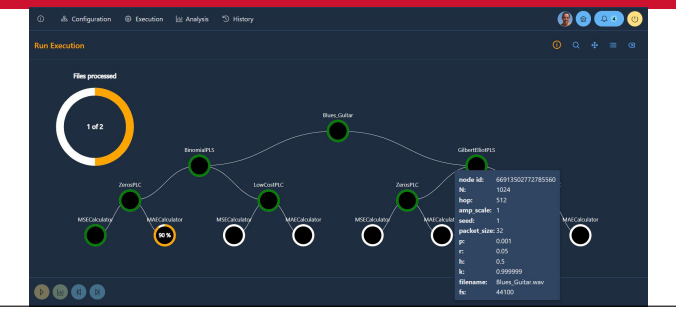
Now time has come to have a look at the application interface.
This is the landing page which addresses two main purposes. One Is providing to the user some useful information about the domain and about the application itself to help him/her to develop a proper mental model of the software. This Is achieved through the panel on the left where a short help page provides a summary of the main PLC related concepts and of what the application can do. The second objective of this page Is to put the user in condition to start using the testbench immediately. To achieved this a list of the most relevant operational Is displayed and a direct entry point to the functions Is provide.

GUI - Configuration Module



This screen instead is intended to guide the user through the collection of the input data to configure an elaboration. The key aspects to be considered in the design were in this case fast and effettive interaction, clarity and adaptability to changes in the underlying testbench library.
Fast interaction was achieved through sensibile defaults for the settings and keyboard shortcuts, while clarity by splitting the configuration process into multiple sequential phases, each focused on a single aspect.
Regarding adaptability the ambition was that the application should be able to deal with PLC Testbench's extensions, like the implementation of new algorithms in whatever module, without needing any change in the code. This could be achieved by exploiting Python introspective functions to analyze at runtime the testbench code, dynamically discovering the supported algorithms and their corresponding settings.

GUI - Execution Module

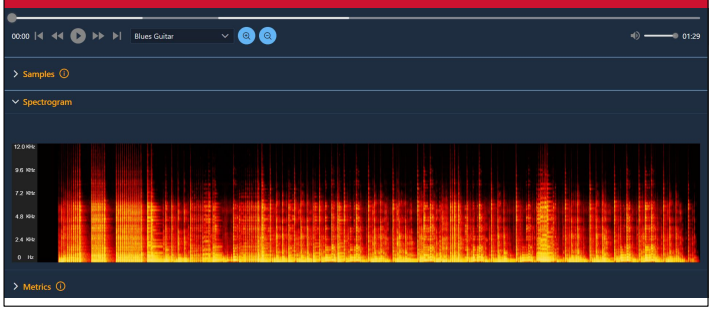


A PLC Testbench elaboration can be represented as a forest of trees, where each tree corresponds to the processing of a single input file.
Depending on the number of input files to be processed, their duration, and the algorithm's parameters, an elaboration can take in some cases a considerabile amount of time. It was therefore very important to give the user the possibility to monitor the progress of the launched elaborations.
Since the structure of the elaborations is by definition identical for all the input files, in order to avoid cluttering the interface with redundant information, progress is displayed at two different levels of detail: overall progress and progress within a single file's processing.
The settings of each elaborations step can be inspected by placing the mouse pointer over the corresponding node.

GUI - Analysis Module - 1

The waveforms of all the version of a given input file, be It the original or a reconstructed one, are displayed on the same chart, together with the lost packets' regions.
Each single waveform can be by shown or hidden by activating or deactivating the corresponding checkbox in the selected audio files dropdown.
Each single audio file can be played through the playback controls and bar below the waveforms chart, to evaluate the perceived quality of the reconstruction.
By brushing with the mousepointer over the chart it is possibile to zoom in on any portions of the file. The zoom operation can be repeated until the desired level of detail is reached.

GUI - Analysis Module - 2

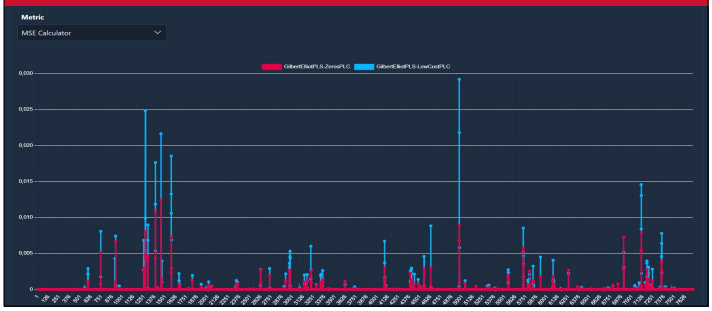


For each audio file, either original or reconstructed, a spectrograms can be displayed, representing the composition of the audio signal over time as a color map, where brighter colors correspond to greater intensity/volume of the corresponding frequencies.

GUI - Analysis Module - 3

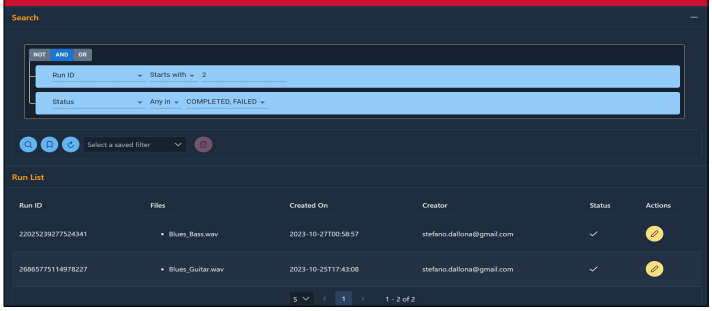
When clicking on a lost packets region, the application displays the detailed waveforms of all the audio signal's reconstructions in a slightly wider area surrounding the lost packets. The single waveforms can be shown or hidden by clicking on the corresponding item in the coloured legend.
It Is possibile to further refine the displayed portions of the file by dragging the handles in the bar below the chart.
The resolution of the diagram can be increased until single audio signal samples can be discriminated.
In this slide the original audio signal is represented in red,
the signal affected by the packet loss is represented in blue and the reconstructed signal in represented in green. The more overlappable the signals, the higher the accuracy of the reconstruction.

GUI - Analysis Module - 4



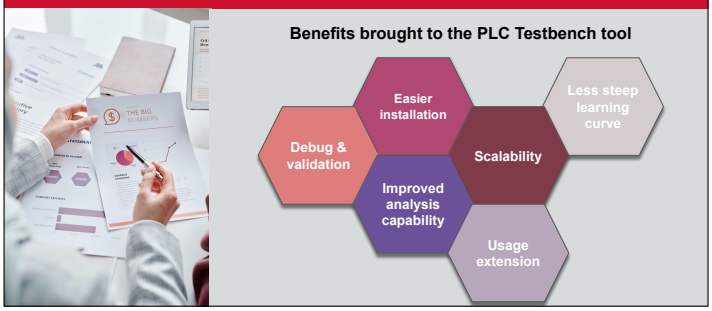
Output metrics are calculated on each original and reconstructed audio file. They can be grouped into two categories: linear metrics, producing a time series for each audio file, and scalar metrics, producing a single value for each audio file.
The data to be displayed can be customized by clicking on the legend items.

GUI - Search Module



The search module allows the user to navigate through the list of the elaborations or to build, save and replay specific queries. Queries can be built visually by combining multiple conditions using logical operators. Each condition can be based on any field of the elaboration or on any setting of the referenced algorithms.

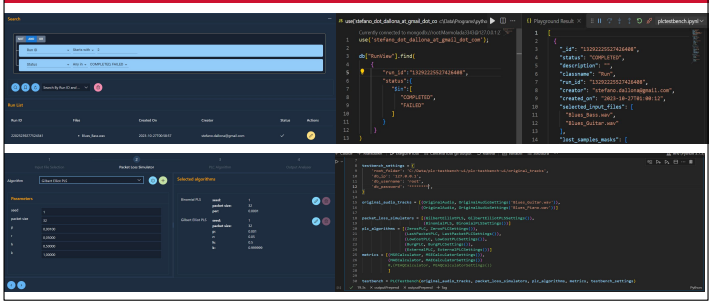
Results



The most relevant advantages brought to the PLC Testbench tool by this thesis work through the development of the Web GUI can be summarized as follows:

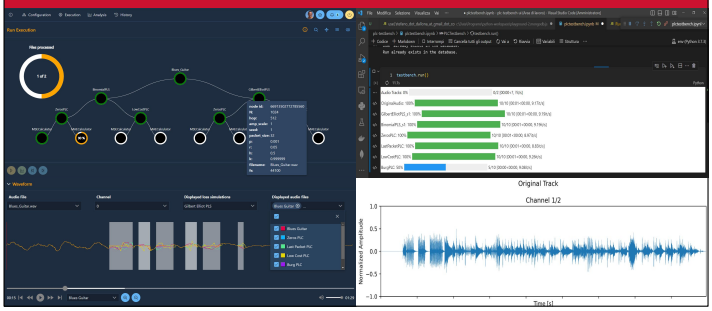
- a through debug and validation of the testbench was carried out as a side benefit of the project
- the analysis capabilities of the tool have been extended and improved in terms of quantity and quality of the information
- the complexity of the tool installation has been completely hidden from the user by abstracting It away in the docker image's build process
- the application has been made more scalable by supporting distributed deployment across multiple computing nodes
- the tool has been made usable also to people with no expertise in Python programming

GUI vs Native Interaction - 1



This slide shows a visual comparison of how the main interactions with the PLC Testbench are handled in the web GUI versus how they are carried out through the native interface.
In the upper half of the slide, on the left we can see how the GUI supports visually building a query to find out the elaborations matching certain criteria. On the right, when interacting directly with the PLC Testbench the same operation has to be performed at programming level by means of a query language.
The same considerations apply to the elaboration configuration as highlighted in the lower part of the slide.

GUI vs Native Interaction - 2



Finally the same comparison has been performed on the progress monitoring and results' analysis use cases.
Also in these case the web GUI provides a more convenient and effettive interaction because it displays the hierarchical structure of the elaboration and it presents the output information in a more integrated way, with the lost regions overlapped to the waveforms.
On the other side, in the native interaction the elaboration's structure is completely flattened and the waveforms and lost packets are represented separately.

Future Work

A few ideas

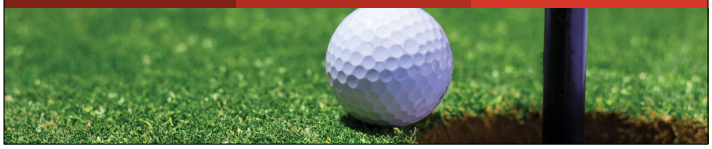
- *Extensive validation with users (*)*
- *Support for additionals audio formats*
- *Exposing logs*
- *Search functions on output results*
- *UI Themes*
- *Support for additional languages*
- *User collaboration use cases*
- *Additional authentication & authorization methods*
- *Data export*

(*) A first preliminary but very positive feedback has been received from experts at the IS2 2023 Conference in Pisa

Despite being fully operational and exposing all the current functions of the underlying PLC Testbench, of course there Is still a lot of room for improvement.
In this slide I try to provider sime indications on possibile future enhancement areas.

Conclusions

PLC Testbench Native interaction	Web GUI
- limited and raw visual output - no output integration - programming-level interaction - installation complexity	- sophisticated visual output - highly integrated output - graphical interaction - installation ease



Finally this slide summarizes the major achievements of this thesis work by highlighting the most critical limitations of the native PLC Testbench's interface and how they were addressed and overcome in the web GUI.

References

GitHub repository of the project
https://github.com/cimil/plc-testbench
public access

Docker image of the project
https://hub.docker.com/r/cimil/plc-testbench-ui
public access

Paper presented at the IS2 2023 in Pisa
4th International Symposium on the Internet of Sounds
https://drive.google.com/file/d/1kFY9Hj-G7mWJP7U3CpPZf9TR95M5tQGV/view?usp=drive_link
restricted access

The result of this thesis work is publicly available in the form of source code at the GitHub URL mentioned in the slide or as a pre-built docker image at the indicated DockerHub URL.
A paper about the jointed work of Ing. Vignati and me for the respective Thesis was presented at the 4th International Symposium on the Internet of Sounds, held in Pisa on the 26-27th of October 2023.
The text of the article will be publicly available when the proceedings of the conference will be published. In the meanwhile it can be consulted through the restricted access link reported in the slide by requesting access.

Prizes

During the conference in Pisa a demonstration of the software took place and led to some very positive feedback from the team of experts evaluating it.
At the end of the conference Ing. Vignati and me had the great honour to be praized with the “Best Demo Award”.