New In Media Stat Virtus Method for Distance Training in Vocal - Instrumental Chamber Music

Handbook for applied technologies

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IN MEDIA STAT VIRTUS
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Introduction

The digital transition is currently experiencing a massive acceleration, significantly impacting higher education in music across Europe, particularly in the context of new methods for organising distance learning and interaction. Immersive technologies now play a crucial role in music performance training, encompassing various stages of learning, evaluation, and connection with the professional world. The IMSV project represents an immediate response to mitigate the digital divide caused by technological insufficiency or lack of training, which hampers the development of essential skills needed for accessing digital learning and could lead to severe artistic isolation soon.

The adoption of blended teaching techniques, which integrate traditional skills with technology-based learning methods, is a fundamental opportunity for creating a broader environmental context. Specifically, in the artistic music sector, this approach facilitates the formation of artistic and technological communities and enhances their interaction. By combining traditional methods with cutting-edge technology, educators can offer a more dynamic and comprehensive learning experience, preparing students for a rapidly evolving digital landscape.

Moreover, the integration of digital tools in music education not only bridges the gap between traditional and modern practices but also promotes inclusivity. Students from various backgrounds can access high-quality education regardless of their geographical location. This democratisation of

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learning resources ensures that talent is nurtured everywhere, fostering a diverse and vibrant musical community.

Needs Analysis

Digital Transition and Digital Skills

The pandemic has accelerated the development of a crucial transversal competence: problem-solving, particularly in response to critical and unprecedented situations. This has been especially evident in performative artistic disciplines, such as chamber music, which require synchronous interaction among participants. The IMSV project aligns with problem-solving methodologies, focusing on developing alternatives to traditional teaching, evaluating available technological resources, selecting viable alternatives, and implementing corresponding solutions.

As a starting point, the IMSV project has conducted an analysis of existing problems, defining its intervention field through the collaboration and active participation of involved partners. This collaboration aims to construct a model for remote interaction among musicians, introducing a new teaching tool that leverages technology to facilitate the learning of chamber music. This objective, tested within the IMSV project, aims to foster the growth of broader educational and artistic communities, enhancing the exchange of knowledge and strengthening teaching and learning processes.

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By addressing these challenges head-on, the IMSV project not only provides immediate solutions but also sets the groundwork for long-term improvements in music education. The insights gained from this initiative can be applied to other areas within the arts, encouraging a holistic approach to digital education. This project ultimately seeks to empower educators and students alike, ensuring that the transition to digital learning is both effective and enriching.

Elements of Innovation

Distant Interaction

The IMSV project addresses the critical issues related to technology by proposing an efficient approach to experimenting with real-time performance situations. This includes managing sound reverberation within the physical environment and the ability to remotely handle visual feedback, which is crucial for cohesion and interpretation. The technological requirements for effective remote practice of chamber music, along with the necessary hardware and software to ensure high-quality audio in remote or mixed sessions, are proposed and analysed. Thus, IMSV situates itself within the broader field of Networked Music Performance.

Networked Music Performance refers to a set of real-time interactions over a network, allowing geographically distant users to rehearse and perform as if they were in the same room. Current music performance is often hindered by delays and latencies in real-time audio transmission.

Therefore, the quality of the connection is a fundamental requirement for successful implementation. Remote interaction also depends on hardware and software that ensure quality audio in both remote and mixed sessions.

Regarding Partial PlayBack, the IMSV project aims to create a user-friendly interface that allows musicians to interact by studying or overdubbing while the software plays one or more audio tracks. This feature, highlighted during the pandemic, has proven to be highly effective for educational purposes, particularly in the initial phases of learning and repertoire consolidation. It also supports the development of self-assessment skills. The ability to play along with pre-recorded tracks enables students to focus on specific aspects of their performance, such as timing, intonation, and dynamics, in a controlled environment. This method not only enhances individual practice sessions but also prepares musicians for collaborative work in a remote setting.

Furthermore, the IMSV project aims to establish a framework for synchronous musical performance, enabling chamber music groups to perform together in real-time despite being in different locations. This involves the development of advanced latency compensation techniques and high-fidelity audio transmission protocols. By leveraging these technologies, IMSV seeks to decrease the geographical distances between musicians, fostering a more interconnected and collaborative musical community. The project also explores the potential for integrating video streaming with audio performance, providing a more immersive and cohesive experience for both performers and audiences.

Guidelines and Handbook for Training in the Field of Ensemble Music

The Handbook developed in IMSV is the practical companion of the project Guidelines. The guidelines are aimed at academic teachers with the objective of disseminating and developing this method among trainers in the field of ensemble music, supported by examples and case studies. This approach will increase the spread of good practices in blended chamber music teaching and distance learning. By incorporating real-world scenarios and practical applications, the guidelines help educators adapt to the evolving landscape of music education, ensuring that students receive a comprehensive and relevant training experience.

Additionally, the guidelines include training actions specifically aimed at students. This comprehensive approach ensures that both teachers and students are well-equipped to adopt and benefit from innovative methods in ensemble music training. The aim is to provide detailed instructions on using the technological tools and platforms introduced by IMSV, fostering self-sufficiency and confidence in navigating the digital aspects of musical education.

Moreover, the guidelines emphasise the importance of continuous feedback and assessment. By utilising digital tools for real-time feedback, educators can provide immediate and constructive criticism, helping students to improve their performance more effectively. This iterative process of practice and feedback not only enhances learning outcomes but also encourages students to engage more deeply with their studies. However, the technical approach to the IMSV method is fully

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developed in the Handbook. The role of this book is to provide technical support in the use of technologies mentioned in the Guidelines.

In summary, the IMSV project not only addresses the immediate challenges posed by remote music performance but also lays the groundwork for long-term advancements in music education. By integrating innovative technologies and methodologies, IMSV aims to create a more inclusive, effective, and dynamic learning environment for musicians. This initiative represents a significant step forward in bridging the gap between traditional music education and the digital age, ensuring that future generations of musicians are well-prepared for the evolving demands of their profession.

Technologies and Teaching of Ensemble Music

IMSV incorporates three key technology-related aspects in its approach to enhancing the teaching and practice of ensemble music:

- **Synchronous and Remote Music** – This paragraph addresses the potential for synchronous remote music-making using data networks. This capability is closely tied to the development of new methodologies for music teaching, allowing musicians to rehearse and perform together in real-time despite being geographically separated. The focus is on overcoming challenges such as latency and ensuring a seamless experience that mimics in-person collaboration.

- **Hardware and Software** – This paragraph analyses, studies, and identifies the necessary requirements to ensure quality audio during remote or mixed sessions. The goal is twofold: to enhance the practice of ensemble music and to open new educational possibilities. IMSV outlines a set of hardware requirements categorised into different accessibility levels, enabling musicians and institutions to equip themselves with the essential technological tools needed for the best possible audio experience. These requirements include high-quality microphones, headphones, mixers, speakers, sound cards, and Digital Audio Workstations (DAWs). By providing detailed specifications, IMSV helps ensure that both amateur and professional musicians can participate in high-fidelity remote sessions.
- **Experimentation with audio software** – This part focuses on providing a user-friendly interface with a series of controls that can be operated during performance. These controls allow musicians to adjust parameters such as tempo, dynamics, and articulation in real-time, thereby customising their performance. The computational power of modern PCs, combined with advanced software, enables performers to explore new approaches to music production and rehearsal. This includes the ability to manipulate multi-track audio, alter time and pitch in real-time using sophisticated algorithms, and interact with pre-recorded tracks to create a more dynamic and personalised rehearsal experience.

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Technologies for Ensemble Music

The IMSV project integrates various technologies to support ensemble music, necessitating some basic technological equipment such as computers, webcams or cameras, microphones, headphones, mixers, speakers, sound cards, and DAWs. The project also leverages numerous platforms and applications to facilitate synchronous remote practice. These tools are essential for maintaining the integrity of ensemble rehearsals and performances at a distance.

Key platforms and applications used during the IMSV project include:

- **Reaper**[1] – A powerful Digital Audio Workstation used for recording, editing, and mixing audio.
- **Logic** – Commercial Digital Audio Workstation for professional music production.
- **Listento** – A commercial app that enables real-time audio streaming for remote collaboration.
- **Jamulus**[2] – Software that allows musicians to play together in real-time over the internet.
- **ForScore**[3] – An app for digital sheet music management for MacOS
- **Kontakt**[4] – A sampler used for creating and playing virtual instruments.

[1] https://www.reaper.fm/
[2] https://jamulus.io/
[3] https://forscore.co/
[4] https://www.native-instruments.com/en/products/komplete/samplers/kontakt-8-player/

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- **Zoom[5], FaceTime, Google Meet, Skype, and WhatsApp** – Video conferencing tools that facilitate visual and auditory communication.
- **Google Drive, Dropbox, and WeTransfer** – Platforms for sharing large files, such as audio and video recordings.
- **Photo and video editing apps** – Tools for creating and editing multimedia content.

- **Pro Metronome and Pulse** – Metronome apps that help musicians maintain tempo during practice.
- **YouTube, IMSLP[6], MuseScore[7], and Spotify** – Platforms for accessing a wide range of musical resources, including scores and recordings.
- **PageFlip Firefly** – A Bluetooth pedal for hands-free page turning of digital sheet music.
- **Doodle** – A scheduling tool to coordinate rehearsal times among participants.

These technologies collectively enhance the learning and performance experience for ensemble musicians, providing them with the tools necessary to adapt to the evolving digital landscape of music education. By integrating these tools, IMSV aims to create a comprehensive, flexible, and

[5] https://zoom.us/download
[6] https://imslp.org/
[7] https://musescore.org/en/download

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accessible environment for remote music collaboration, ensuring that musicians can continue to develop their skills and perform together regardless of physical distance.

New Perspectives for Blended Learning

The integration of technological resources into ensemble music pedagogy facilitates a fresh approach, introduces new considerations, and offers a novel perspective on music instruction as a whole. IMSV presents a methodology centred on various distance learning techniques. These include tutorials, Networked Music Performance, multitrack recordings, sampled sounds, score sharing, and Partial PlayBack or exchanging materials, among others. These methods can be complemented by additional educational strategies such as contextualising pieces stylistically and historically, analysing interpretations, and more.

The outcomes achieved through self-directed learning with the assistance of PPB exemplify the significance of merging technology with traditional teaching methods. Hybrid models, which combine digital instruction with in-person classes (such as blended learning, flipped classrooms, and flexible learning), should serve as innovative educational models. Through the utilisation of immersive technologies and virtual augmented reality, these models are poised to influence the training of classical musicians and the emergence of new aesthetic paradigms.

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Music Repertoire - which Music Genres and Aesthetics?

IMSV's innovative approach enables the integration of traditional instrument sounds with sampled sounds. This integration is particularly valuable for instruments associated with specific historical periods like mediaeval and baroque music. By digitally sampling rare or obscure instruments, IMSV broadens the repertoire available for study and performance.

Numerous case studies demonstrate the successful interaction between traditional and sampled instruments in various ensemble formations. These studies explore a diverse range of musical genres, including classical, pop, and rock, showcasing the versatility of IMSV's methods in different musical contexts. Through these explorations, IMSV promotes the cross-pollination of musical styles and expands the creative possibilities for musicians across genres.

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The Structure of this Document

The project aims to showcase cutting-edge distance learning methods for both vocal and instrumental chamber music instruction at the academic level. It seeks to offer comprehensive guidance to academic instructors on the implementation of these methods, supplemented by case studies and illustrative examples. Referred to as the "IMSV method," this approach primarily relies on two key technologies:

1. Networked Music Performance (NMP)
2. Partial PlayBack (PPB)

NMP technique represents a technological advancement in music training, and the only technical solution for synchronous blended learning in ensemble music training. However, technical problems and lack of training in NMP could push teachers and trainers to use a simpler and well-established solution, and choose asynchronous blended learning based on PPB instead of the synchronous NMP technique. In the first part of the handbook, we explore in detail the use of NMP technique, while in the second part of the document, we concentrate on tools for optimal PPB and general recording. Of course, the hardware solutions for PPB can be successfully applied in the first part. In addition to these core technologies, various technical supports are available to enhance the learning experience. These include tools for contextualising musical pieces, sharing scores, editing parts, proposing interpretations, suggesting technical solutions (such as fingerings), and more. These resources, explored in the third part of the Handbook, aim to enrich the educational process and facilitate effective music instruction, even in remote settings.

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Part 1 – Synchronous Music-Making by Networked Music Performance

1.1 Introduction

The rapid evolution of technology and the subsequent proliferation of digital communication networks have transformed our communication experiences, bridging virtual distances with unprecedented efficiency. Harnessing the potential of these advancements, the EU-funded Virtual Stage project seeks to pioneer innovative tools for distance music education, aiming to integrate them into remote environments tailored for music interaction and instruction. Among the array of techniques earmarked for distance learning within this initiative, special emphasis is placed on Partial PlayBack and Networked Music Performance, with a predominant focus on the latter.

Networked Music Performance represents a dynamic frontier of ongoing research, converging technology with contemporary, popular, and electronic music genres. This convergence has formed the bedrock of computer-based communication in the realm of music. As networking transcends conventional communication paradigms, morphing into a shared virtual space that thrives on bodily presence and interaction, traditional notions of chamber music, defined by its intricate spatial and temporal dynamics, undergo profound metamorphosis under the auspices of NMP. Categorised based on temporal (synchronous/asynchronous) and spatial (co-located/remote) dimensions, NMP systems aim to facilitate real-time synchronous musical interactions among musicians separated by geographical boundaries. The overarching objective is to simulate immersive environments conducive to a wide spectrum of musical activities, ranging from tele-auditions, remote teaching, and rehearsals to distributed jam sessions and concerts. However, the complexity of musical interactions necessitates meticulous consideration. Musicians accustomed to practising in physical proximity rely not only on auditory cues but also on the ambient reverberations within their environment and visual cues gleaned from the movements and gestures of fellow performers.

The preliminary research on NMP endeavours to unravel the intricate technological challenges inherent in facilitating quasi-real-time performances among musicians situated in disparate locations, with a particular spotlight on professional and pre-professional training within the operatic milieu. The disruptive impact of the Covid-19 pandemic on music education, particularly at the tertiary level, has underscored the urgency for innovative solutions in distance and blended learning methodologies. Consequently, the NMP approach emerges as a potent catalyst for this research endeavour, set within the framework of the EU-funded Erasmus+ project, Virtual Stage[8] and enhanced during the IMSV project. With the objective of empowering music educators with comprehensive guidelines for orchestrating virtual exchanges in chamber music practice and vocal training, this project underscores the pivotal role of Partial PlayBack and NMP techniques, with a

[8] Virtual Stage - Reference No:2020-1-IT01-KA226-VET-008970 – Erasmus+ Key Action 2 – KA226

concerted emphasis on the latter. Rottondi et al. have meticulously reviewed the use of NMP technologies, encapsulating their findings in the following table[9].

Table 1 - The list of NMP solutions according to Rottondi et al. (2016).

Authors	**Name**	**Architecture**	**Network range**	**Network protocols**	**Data type**	**#Audio Channels**	**Multi-stream synchro**	**Codec**
Saputra et al.	BeatME	Client-Server	LAN, WLAN	UDP or OSC	MIDI	16 (input), 1 (output).	none	uncompressed
Kurtisi, Gu et al.	-	Client-Server	LAN	RTP, UDP (stream) TCP (session data)	audio	n.a.	NTP	ADPCM, FLAC (real-time) or MP3, MPEG4 (on-demand)
Renwick et al.	Sourcenode	Client-Server	LAN	UDP	MIDI	n.a.	none	uncompressed

[9] Rottondi, C.; Chafe, C.; Allocchio, C.; Sarti, A., *An overview on networked music performance technologies*, IEEE ACCESS, 2016

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Stais et al.	-	Client-Server or P2P	WAN	n.a.	audio	2	NTP	uncompressed
Kapur et al.	Gigapopr	Client-Server	WAN	UDP	audio, video, MIDI	n.a.	n.a.	uncompressed
Wozniewski et al.	Audioscape	Client-Server	WLAN	n.a.	audio	1 (input), 2 (output)	GPS	uncompressed
Sawchuk, Zimmermann, Chew et al.	-	Client-Server	WAN	RTP/RTSP, UDP	audio, video, MIDI	16	GPS, CDMA	MPEGl-4
Akoumianakis et al.	Musinet	Client-Server or P2P	WAN	SIP (signalling), RTP (stream), HTTP (text)	audio, video	any	none	OPUS (audio), H.264 (video)
Carot et al.	Soundjack	P2P	WAN	UDP	audio and video	8	external master clock	ULD, OPUS (audio), uncompressed or JPEG video

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Drioli et al.	LOLA	P2P	WAN	TCP (control) UDP (stream)	audio, video	8	n.a.	uncompressed audio and video
Lazzaro et al.	-	Client-Server (control) P2P (media)	WAN, WLAN	RTP/RTCP, UDP (stream), SIP (signalling)	MIDI	16	RTP/RTCP synchronisation tool	MPEG4
El-Shimy et al.	-	P2P	LAN		audio, video	n.a.	n.a.	
Fischer et al.	Jamulus	Client-Server	WAN	UDP	audio	2	none	OPUS
Caceres et al.	Jacktrip	Client-Server or P2P	WAN	UDP	audio	any	software-based audio resampling	uncompressed
Akoumianakis et al.	Diamouses	Client-Server or P2P	WAN	RTP, TCP/UDP	audio, video, MIDI	any	internal metronome stream	uncompressed audio, MJPEG video

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Gabrielli et al.	WeMust	P2P	LAN, WLAN	TCP or UDP	audio, MIDI	12	software-based audio resampling	uncompressed or CELT
Meier et al.	Jamberry	P2P	WAN	UDP	audio	2	external master clock	OPUS
Chafe et al.	StreamBD	P2P	WLAN	UDP, TCP	audio	any	none	uncompressed

1.1.1 Short NMP Software Review

Several software applications listed in the table were instrumental in the development of the InterMUSIC project. Among these, notable mentions include:

- **JackTrip** – Developed by the SoundWIRE research group at CCRMA, JackTrip facilitates bidirectional music performances. It operates on uncompressed audio transmission via high-speed links like Internet2. However, the current version lacks support for video transmission.

- **LOLA** – The brainchild of the Conservatory of Music G. Tartini in Trieste, in collaboration with the Italian national computer network for universities and research (GARR), LOLA relies on low-latency audio/video acquisition hardware. It optimises all necessary steps for transmitting audio/video content through dedicated network connections.

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- **UltraGrid** – An open-source software, UltraGrid enables low-latency transmission of audio/video. Although its performance may not match that of LOLA, UltraGrid offers greater flexibility for use with generic hardware and networks. Moreover, it empowers contributors to implement new functionalities, enhancing its adaptability and versatility.

These software tools have played pivotal roles in advancing the capabilities of NMP projects, facilitating seamless audio and video transmission across remote locations. Their contributions have been invaluable in realising the vision of interconnected virtual music performance environments.

1.1.2 The Framework of Networked Music Performance

A musical performance manifests when two or more entities engage in musical interaction through a shared medium. These entities may include musicians during a rehearsal, as well as instructors and learners. To accommodate a myriad of potential scenarios, performances can unfold with all participants in the same physical space (local performance), dispersed across geographical distances (networked performance), or with a combination of both (mixed performance). Interaction between participants is facilitated through a designated medium. In local performances, this medium is physical, such as the propagation of sound through air. Conversely, networked performances rely on digital infrastructure, utilising Internet connectivity and specialised NMP software/hardware to link participants. Mixed performances entail the utilisation of both physical and digital mediums.

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1.2 Materials and Methods

The NMP methodology adopted in the IMSV project centres on Jamulus, a free and open-source software developed by Volker Fischer et al.[10] in C++. Jamulus empowers live rehearsals, jam sessions, and performances with musicians situated anywhere on the internet. This software is hosted on SourceForge under the GNU General Public License (GPL) and is compatible with Linux, Windows, and MacOS operating systems. Built on the Qt framework, Jamulus utilises the OPUS audio codec[11].

The fundamental architecture of Jamulus comprises a server-client model. A central server, equipped with Jamulus server software, aggregates audio data from each connected client, mixes the audio streams, and redistributes the composite mix to all participants. This process is schematically illustrated in the accompanying figure.

At its core, Jamulus employs a callback-based audio interface to capture audio sample blocks from diverse sources such as USB microphones, MIDI interfaces, or audio card outputs. These sample blocks are encoded using the OPUS codec[12] to minimise latency and transmitted over the internet

[10] V. Fischer, "Case Study: Performing Band Rehearsals on the Internet With Jamulus".
[11] J.-M. Valin, G. Maxwell, T. B. Terriberry, K. Vos, High-Quality, Low-Delay Music Coding in the Opus Codec, Accepted for the 135th AES Convention, 2013.
K. Vos, K. V. Sorensen, S. S. Jensen, J.-M. Valin, Voice Coding with Opus, Accepted for the 135th AES Convention, 2013.
K. Vos, A Fast Implementation of Burg's Method, 2013.
[12] https://en.wikipedia.org/wiki/Opus_(audio_format), https://opus-codec.org/

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via the User Datagram Protocol (UDP). The server employs a series of jitter buffers to manage asynchronous network packets received from all connected clients. Within the server processing loop, data packets from individual clients are extracted from the jitter buffer, decoded, and blended to produce a unified mix. This amalgamated mix is then compressed using OPUS and disseminated to all connected clients via UDP packets. Upon reception, these packets are stored in jitter buffers on client devices. During subsequent audio interface callbacks, network packets are retrieved from the jitter buffer, decoded, and relayed to the sound card for output[13].

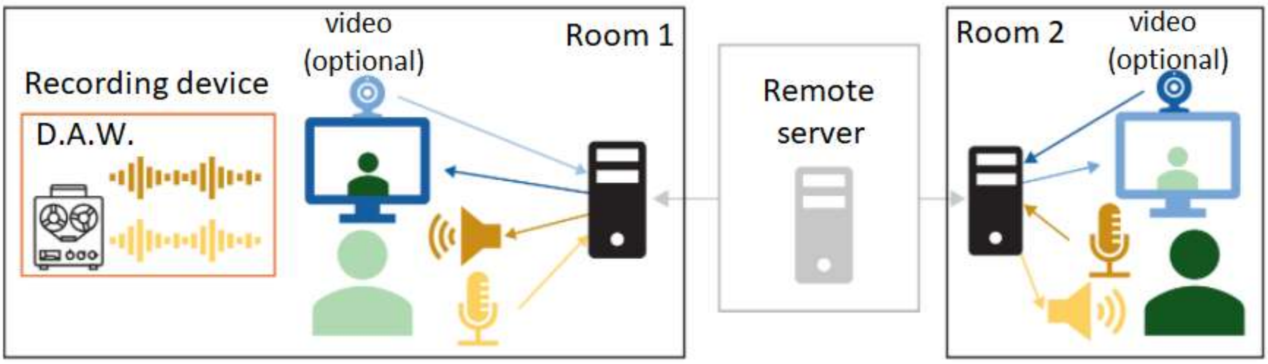

Figure 1-The structure of a served based NMP rehearsal. The users are also connected by video call (without audio) and one of the users connects the NMP platform to a DAW for audio recording.

[13] Fischer, "Case Study: Performing Band Rehearsals on the Internet With Jamulus".

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1.2.1 Installation of the Experimental Setup

Setting up Jamulus across multiple platforms is a relatively straightforward process, as outlined on the software's website. Depending on the user's hardware preferences, input and output selections can be configured within the ASIO settings.

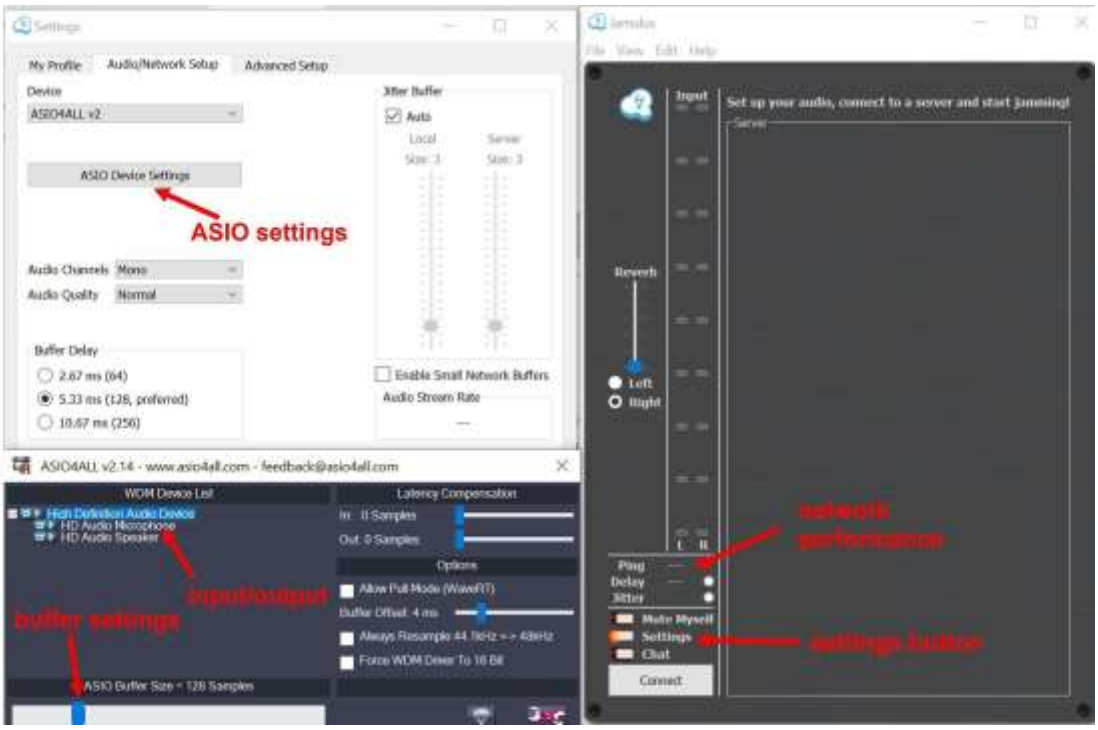

Figure 2 - The main panel (mixer) of Jamulus on the right side, with the audio settings on the top left and ASIO4all setting on the bottom left.

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In the framework of IMSV project we used three different audio setup for NMP with Jamulus:

- **Basic setup –** PC or laptop with budget headphones (wired) and integrated microphone integrated (or wired). PC configs: Windows / Linux / Mac OS.
- **Medium setup –** PC or laptop with quality headphones, fast wireless internet connection, USB external microphone.
- **Advanced setup –** PC or laptop with quality headphones, fast internet cable connection, external audio board, USB external microphone, the PC is routing the audio stream from Jamulus to a DAW.

Measuring the speed of the internet connection is a good way to establish if NMP technique can be successful. The free service by Ookla[14] can be used to achieve this task. The test shows the ping in ms, download and upload speed in Mbps. In order to achieve a decent NMP session, the authors recommend at least a download speed of 60 Mbps.

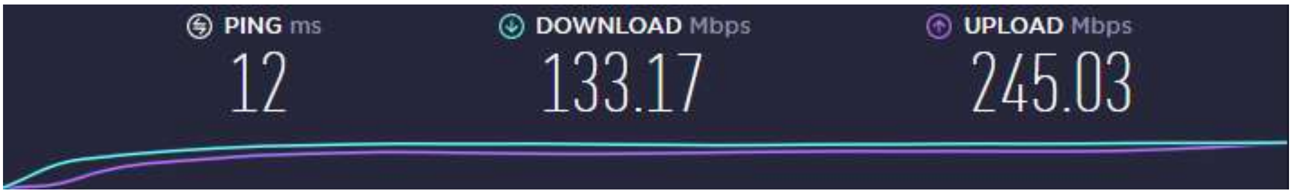

Figure 3 - The result of a speedtest on the free platform Ookla performed in Lyon (France) during a NMP test.

[14] http://www.speedtest.net/

Figure 4 - The result of a speedtest on the free platform Ookla performed in Geneva (Switzerland) during a NMP test.

Speedtest results illustrated by Figure 3 and 4 show optimal conditions for NMP tests. Both of the connections are based on optical fibre.

Simple Tutorial for the students for beginning to work with Jamulus in Mac os System and Windows.

1. Go to https://jamulus.io/ and download the free app for you running system.

Figure 5- The installation process on Jamulus website.

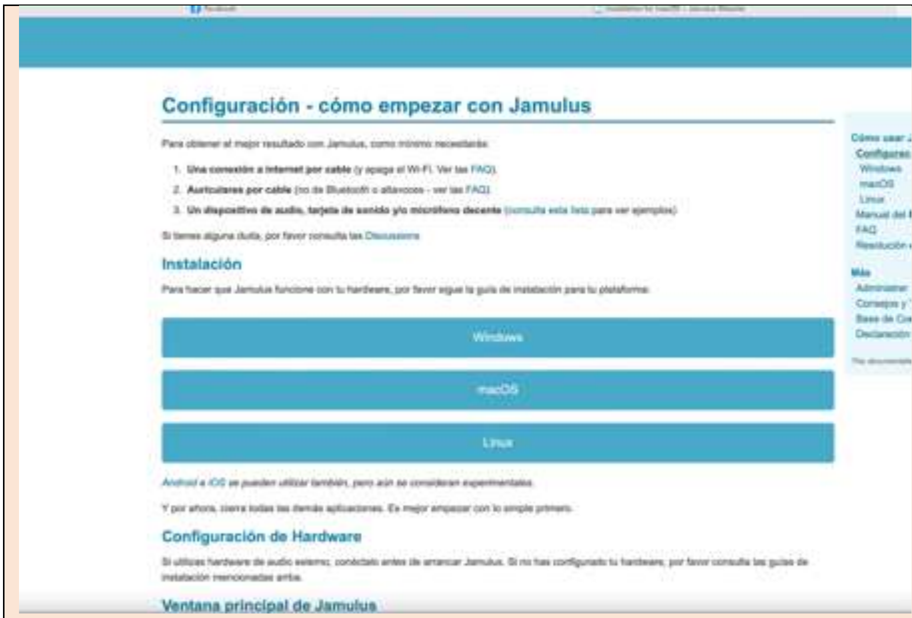

Figure 6 - Multiplatform choice on Jamulus webpage.

2. Download and Run the application and accept the terms.

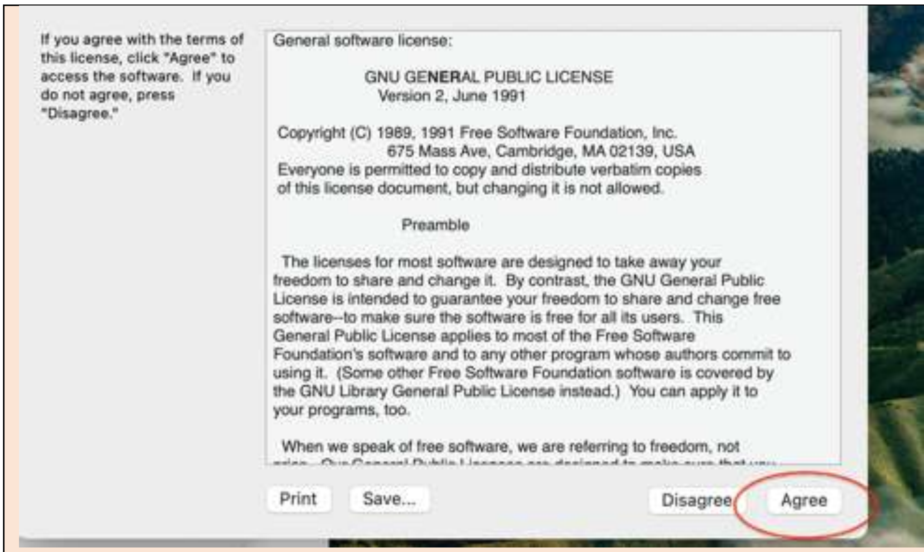

Figure 7 - Finalisation of the installation process.

3. Put the app on the applications file.
4. Run the app and check the microphone and phones. It’s better to connect an external microphone and phones for better sound and coordination.

Figure 8 - The main window of Jamulus mixer.

5. Configure microphone and output.

Figure 9 - Zoom on the settings button on Jamulus mixer

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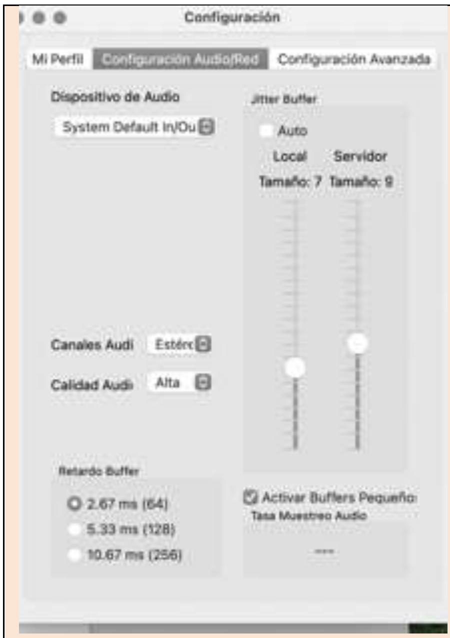

Figure 10 - The configuration window of Jamulus.

6. Click the Audio devices setting (1) and the Buffer in the minimum (2,67 ms).

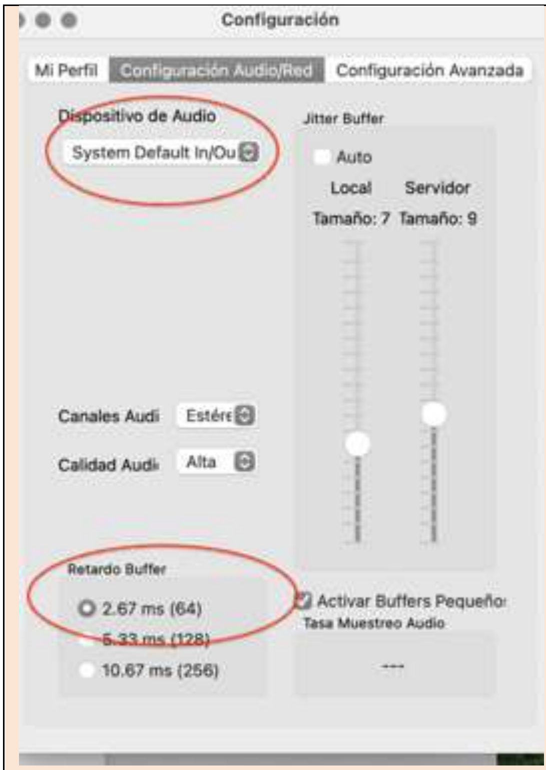

Figure 11 - The audio settings of Jamulus.

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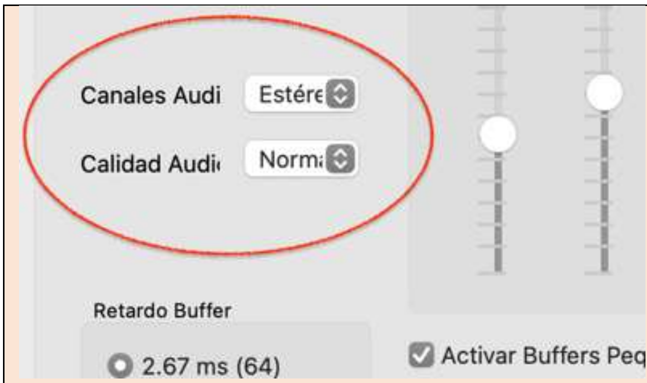

Figure 12 - Choice of audio channels in the configuration panel.

7. Choose Stereo system and medium quality audio.
8. Connect to the servers.

Figure 13 - The connection button on the Jamulus mixer.

9. Choose a server. Try to select one with short delay (in this case, the shorter is Dadá Music in Spain).

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Figure 14 - The list of the available servers appears.

10. Click on the selected server and come in the room (if you enter in a common room you have to ask musicians if you can come before! Enter with MUTE for not disturbing in this case).

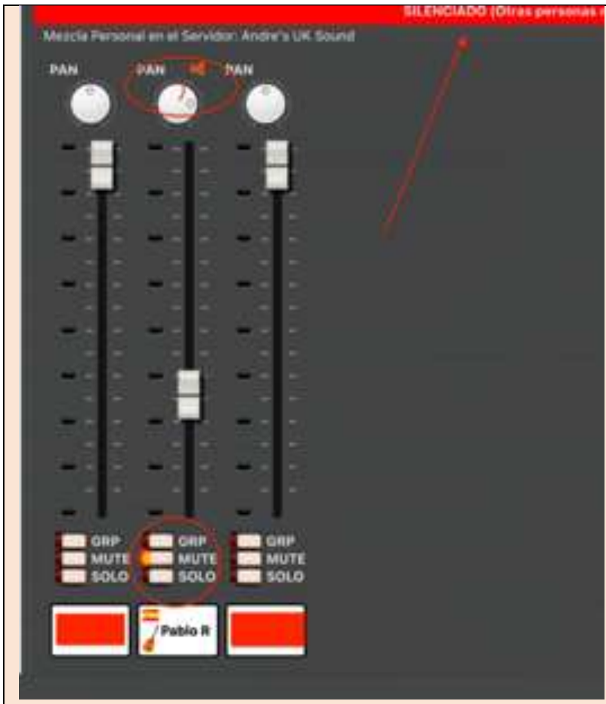

Figure 15 - The fellows musicians appear on the Jamulus mixer.

Normally you have to make corrections on the mic and the volume of your instrument, you have to put your instrument 40 ms approximately distance from the microphone.

Now you can begin to make rehearsals with students or teachers online. Note that the retard doesn't allow fast music and contrapuntal scores.

The instructions below aim at helping a student to install Jamulus on Windows

1. We start the session by Zoom meeting.
2. The student will share his screen to guide him through the installation of Jamulus in Windows.

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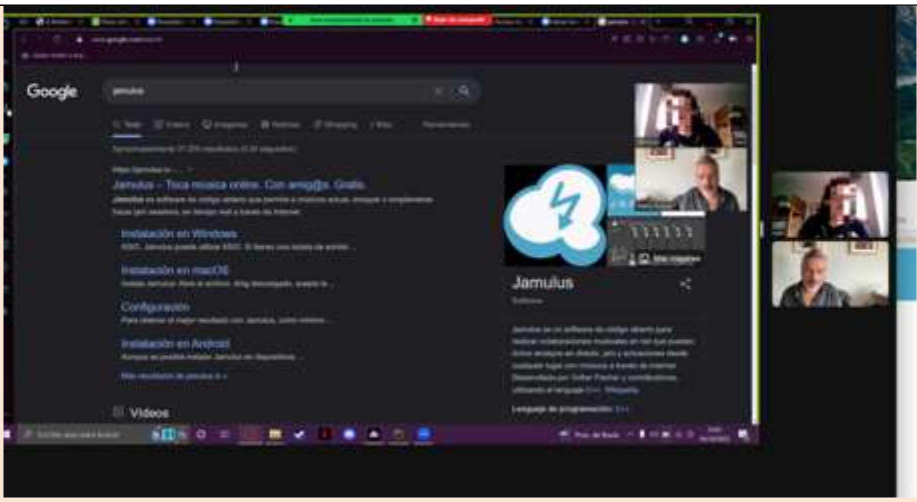

Figure 16 - The tutor help a student in the installation process of Jamulus.

3. Follow the instructions of the short Tutorial online to install Jamulus on Windows.

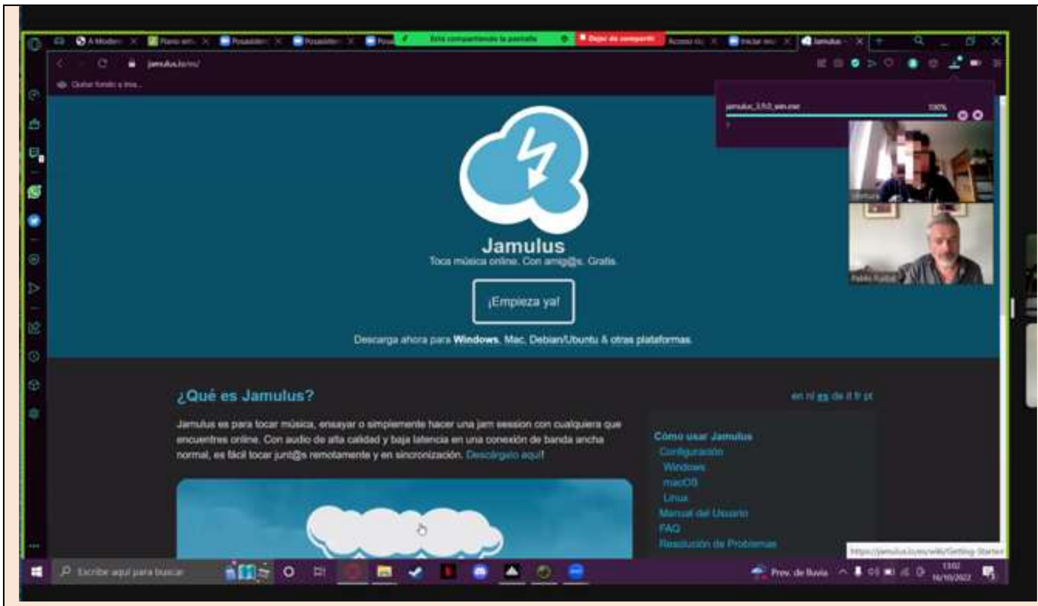

Figure 17- The tutor shows the Jamulus website to the student.

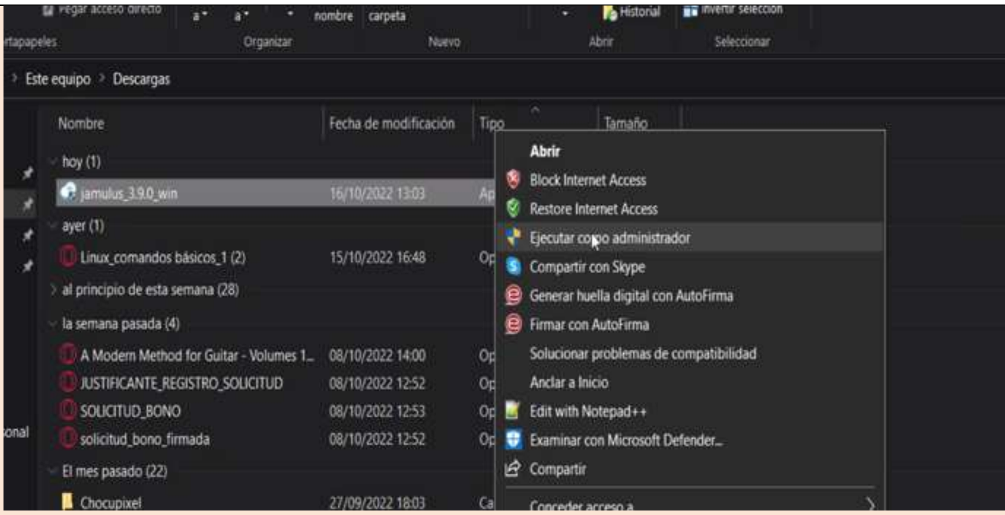

Figure 18 - The downloaded installation file of Jamulus.

4. Download the app and the ASIO driver and follow the instructions.

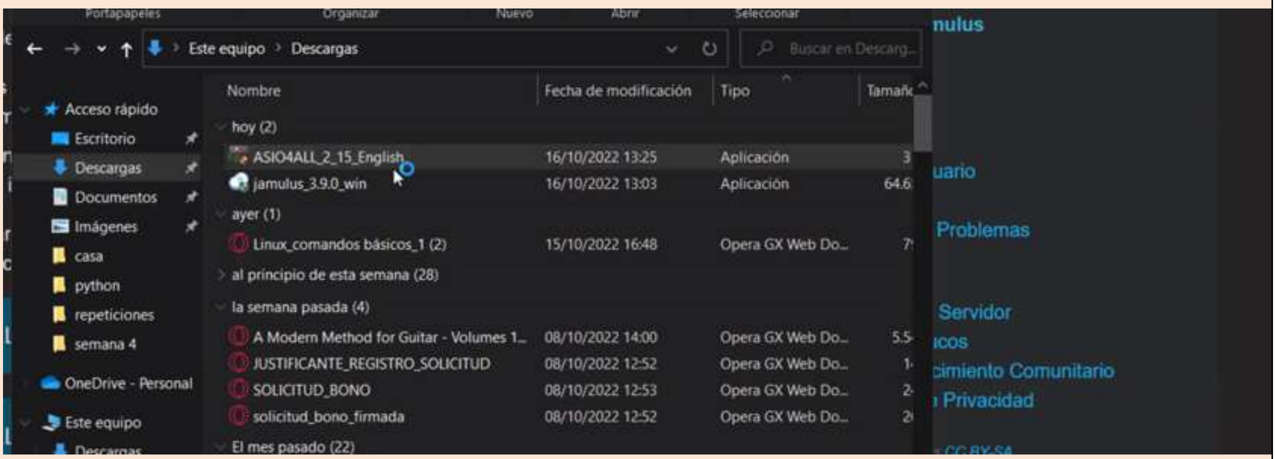

Figure 19 - The downloaded installation file of ASIO4all.

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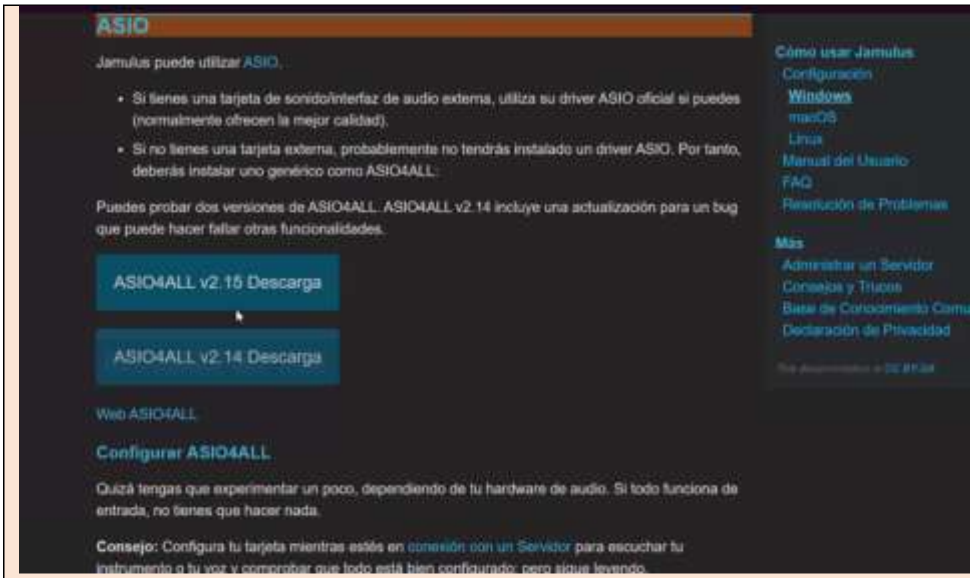

Figure 20 - Multiple versions of ASIO4all, we suggest the latest one.

Figure 21 – If the ASIO driver is not installed, Jamulus asks to install ASIO drivers.

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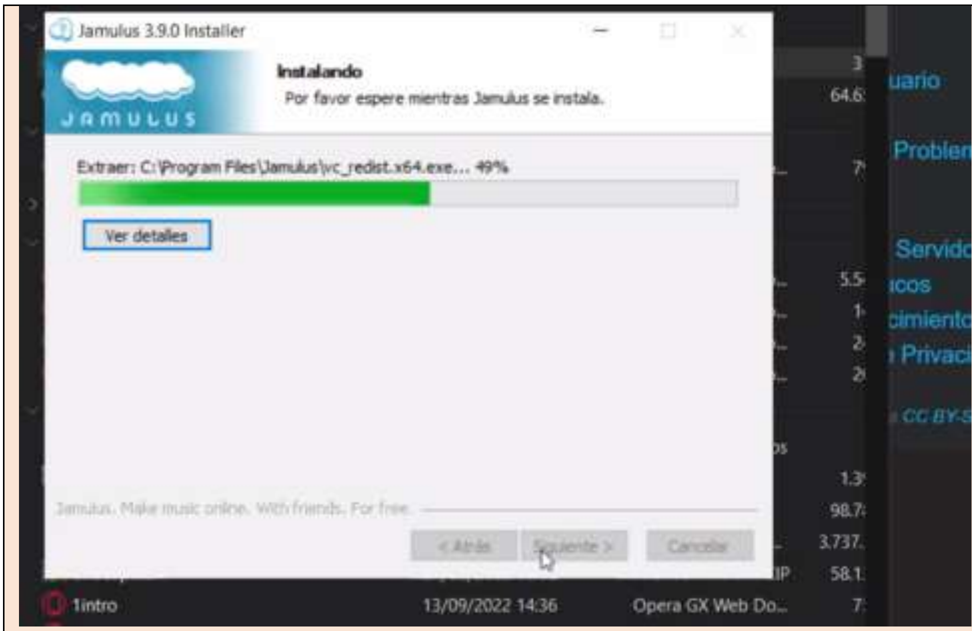

Figure 22 - Jamulus is installing on the computer.

Once the installation of Jamulus is complete, you must configure the audio, which is the most important part of the process. Please follow the instructions below:

1. Connect to the server.

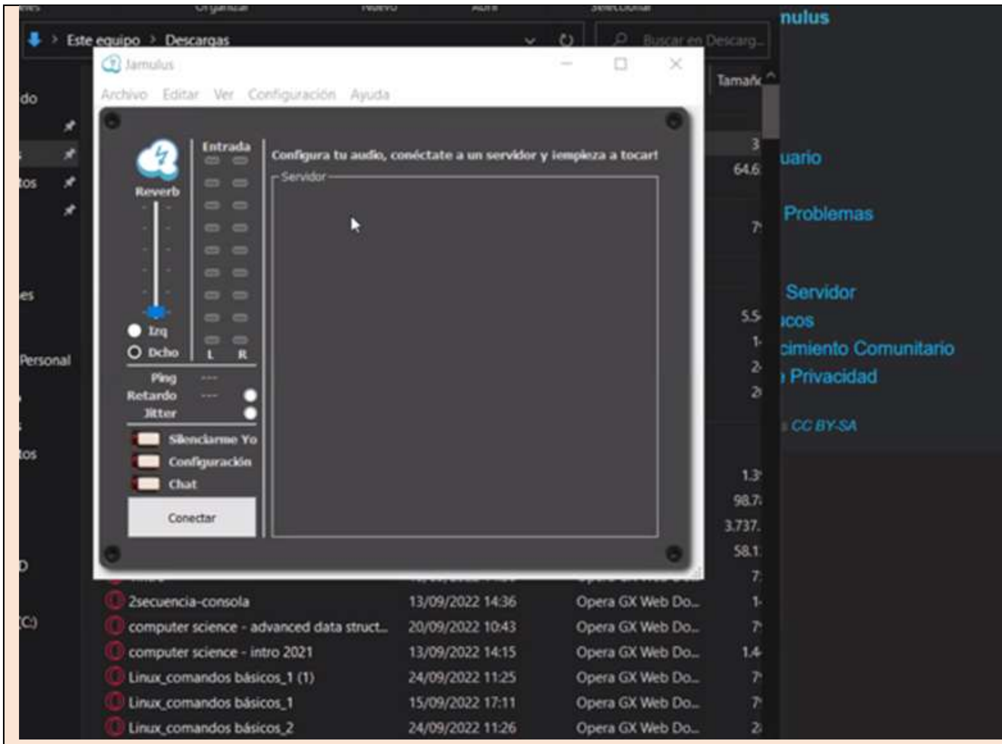

Figure 23 - The Jamulus mixer appears when the program runs.

2. Choose a server that has small latency (in our case we prefer to choose Dadá Music Sound in Spain for better stability.

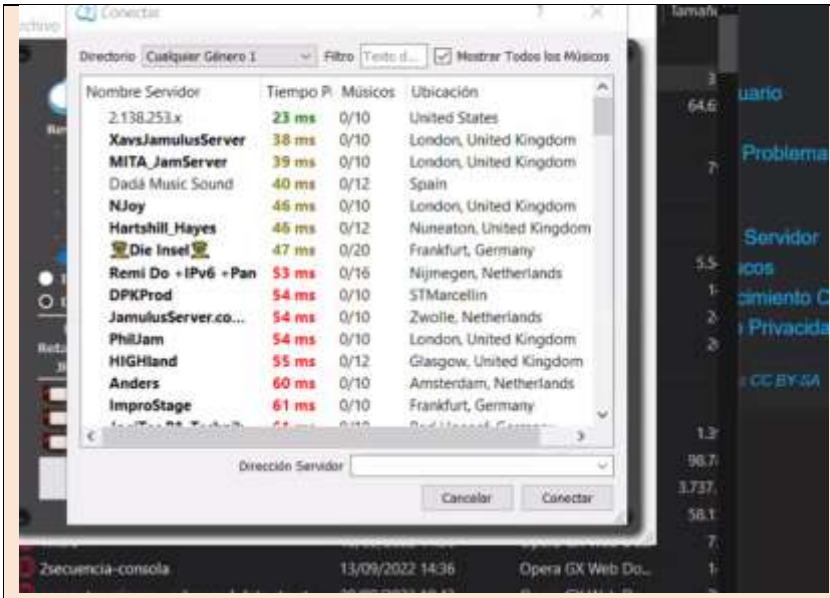

Figure 24 - Once the "connect" button is pressed, the server list popups.

3. We help to configure the audio of the student in remote mode.

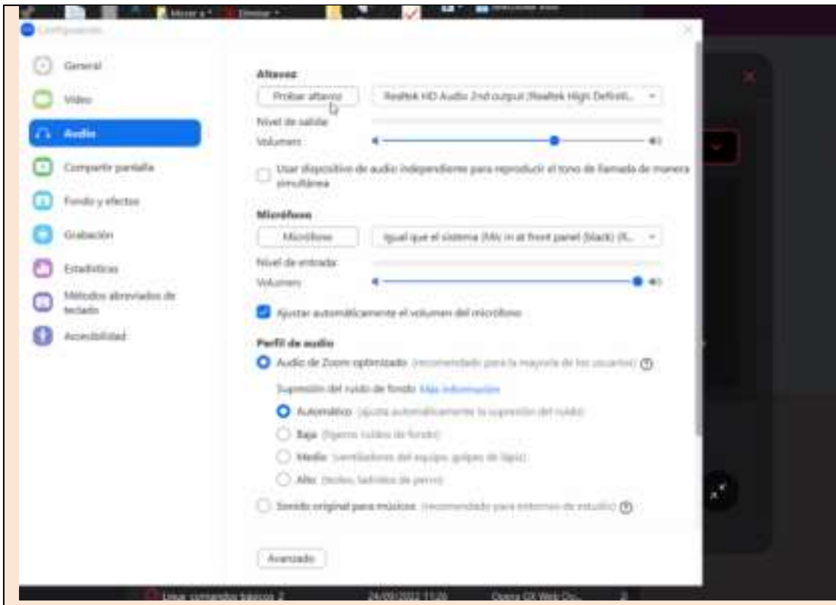

Figure 25 - Since the audio stream is passing through Jamulus, the audio stream from Zoom must be disabled.

To start playing, we enter the same room and check the audio of Jamulus (remember to disconnect audio on ZOOM).

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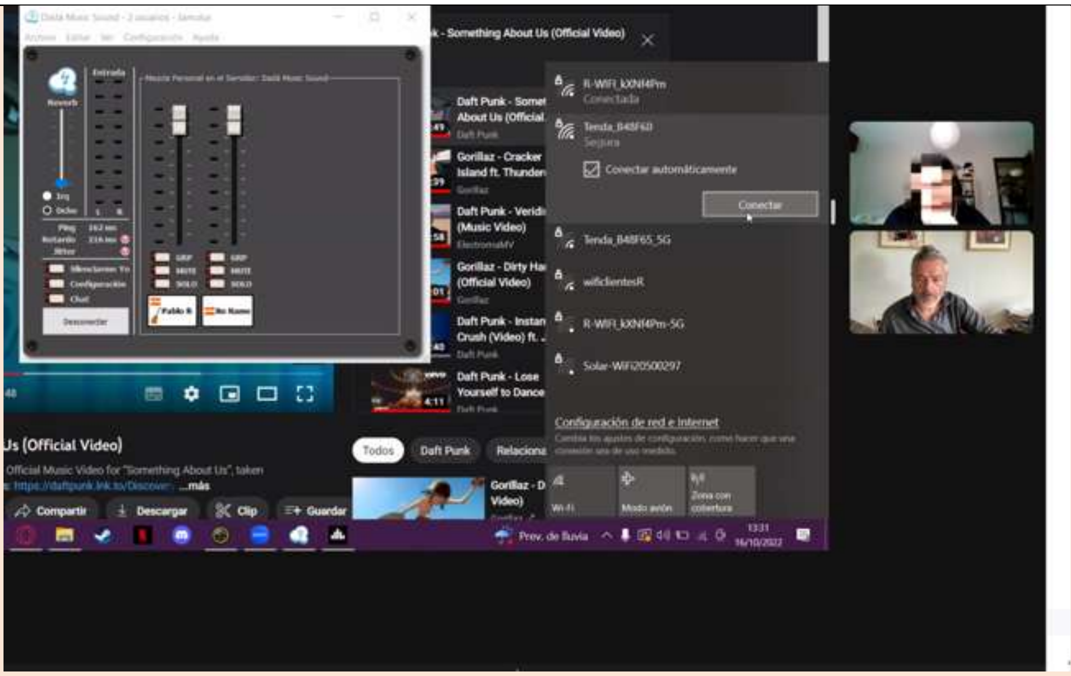

Figure 26 - Once the audio stream from Zoom has been disabled, student and tutor start interacting audio stream on Jamulus.

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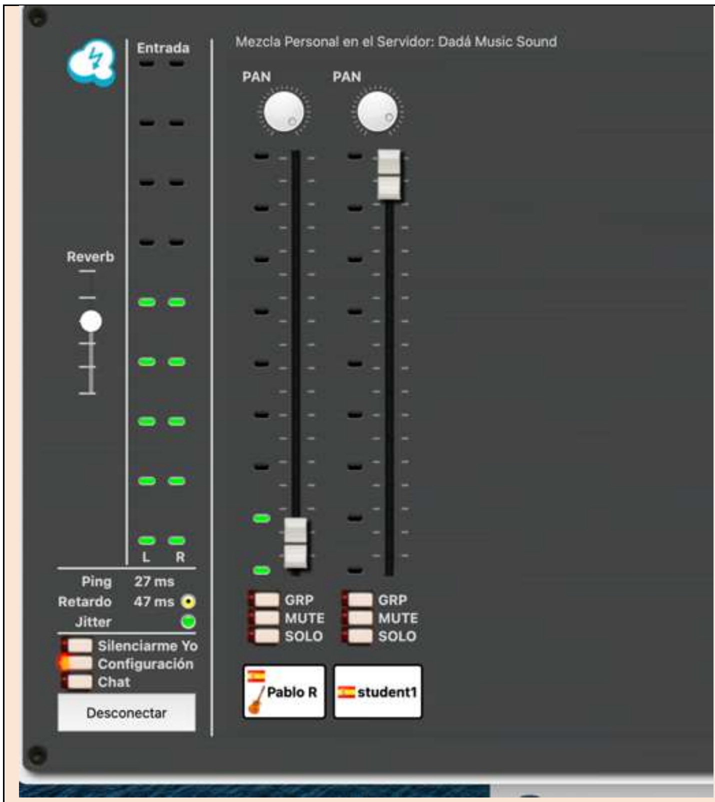

Figure 27- The mixer of Jamulus shows the intensity levels with green bars.

We repeat the sequence with the second student.

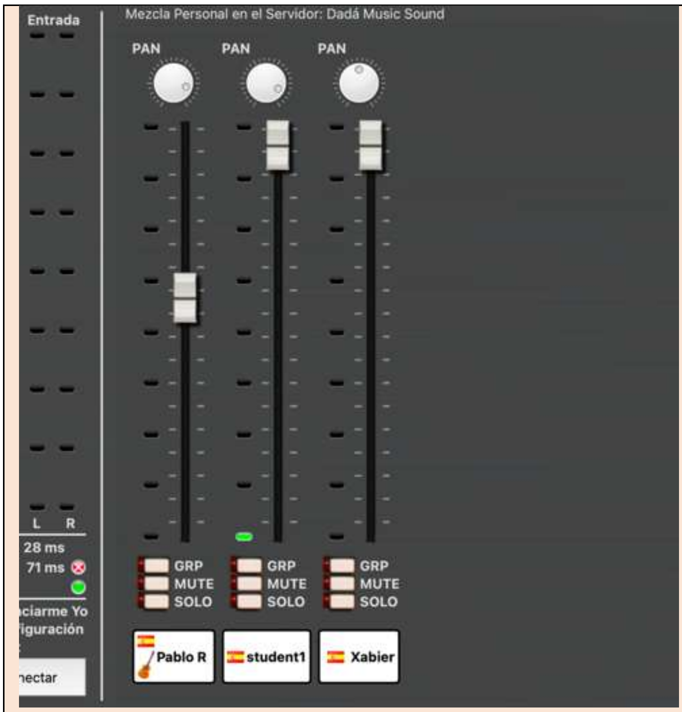

Figure 28 - A second student join the audio space of Jamulus, like in a virtual classroom.

First, we make a scale together to synchronise our sounds both in speed and sound. We mark the difference with a metronome to be aware of the latency.

We can make some exercises together: and simple melody over a harmony and repeat changing the roles.

Then we can read a score first slowly and fasten the tempo.

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1.3 Experimentation in Networked Music Performance

The experimental phase of Networked Music Performance started during the Virtual Stage project for art song classes of conservatory of Firenze (pre-professional training), and continued during IMSV project for instrumental professional instrumental and vocal training.

1.3.1 Pre-professional Training in Art Song Interpretation

Under the guidance of Leonardo De Lisi, professor of Art Song Interpretation at the Conservatory Luigi Cherubini of Florence (Italy), the experimental segment from a pedagogical perspective transpired during the pandemic lockdown in Italy (March 2020 - May 2021). While the volume of collected data may not be sufficient to support comprehensive statistical analysis, the experimentation has nonetheless yielded valuable insights and trends regarding the utilisation of Networked Music Performance within the framework of the Virtual Stage project. This exploration serves as a foundational step towards understanding the potential applications and implications of NMP in music education and professional training.

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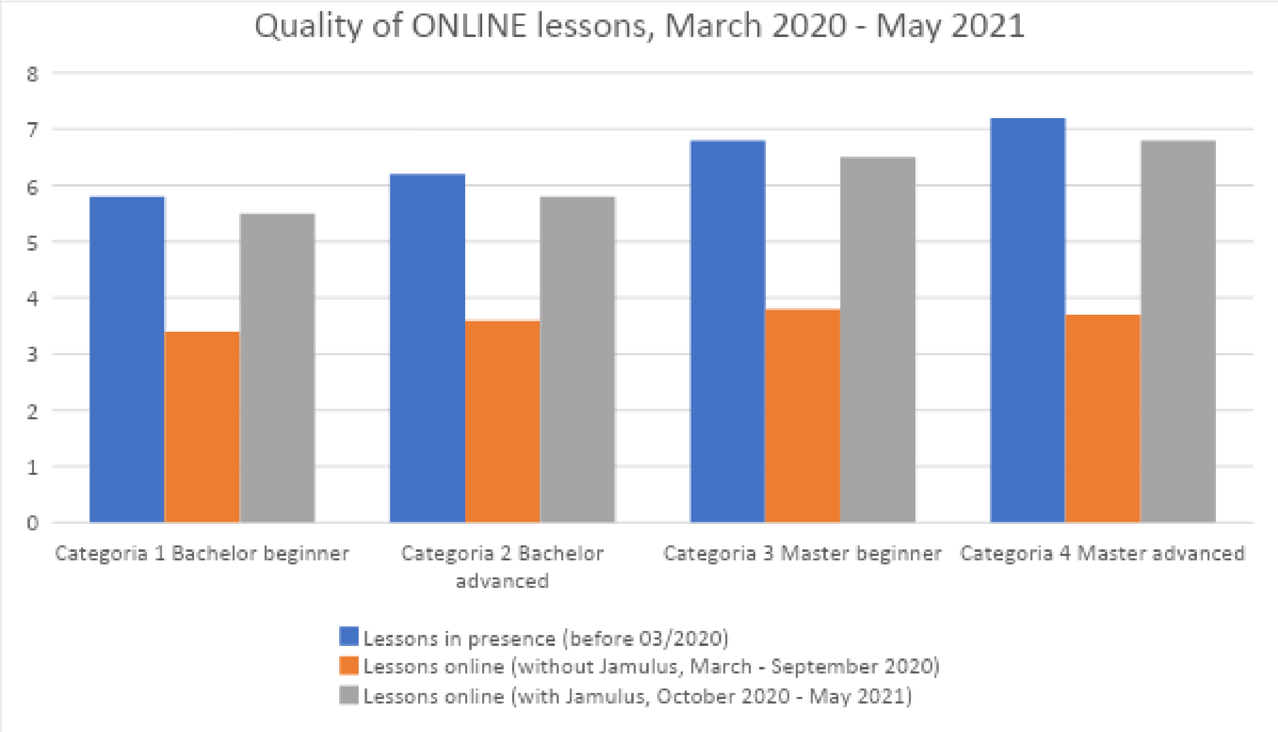

Figure 29 - Results of the survey carried out in the conservatory of Firenze from March 2020 to May 2021.

Throughout the pandemic lockdown period spanning from March 2020 to May 2021, a comprehensive survey was conducted on a cohort of 24 singers enrolled in the "Musica Vocale da Camera" course. This survey, overseen by the instructor, aimed to evaluate academic progress and gather feedback from students across three distinct phases.

The survey timeline encompassed three pivotal periods:

1. **Before lockdown (Before March 2020) –** During this phase, all lessons were conducted in person, with 100% attendance.

2. **During national lockdown (March to September 2020) –** In the absence of Jamulus usage, online lessons replaced traditional face-to-face instruction. The evaluation focused on the effectiveness of these online sessions, accounting for 100% of the remaining scheduled lessons for the academic year 2019-20.

3. **After national lockdown (From September 2020 Onward) –** With the integration of Jamulus technology, online lessons resumed, constituting 50-60% of the scheduled lessons for the academic year 2020-21.

The survey period spanned from December 27, 2021, to January 22, 2022, allowing for a comprehensive assessment of the transition from in-person to online instruction.

The survey group comprised 24 singers distributed across four distinct academic levels:

- **Bachelor beginners (1st/2nd Year) –** Consisting of 7 students embarking on their undergraduate journey.

- **Bachelor advanced (3rd Year) –** Comprising 5 students who had progressed to advanced levels within their undergraduate studies.

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- **Master beginners (1st Year) –** Encompassing 6 students commencing their postgraduate studies.

- **Master advanced (2nd Year) –** Including 6 students in the advanced stages of their postgraduate journey.

This diverse representation ensured a comprehensive analysis of the impact of varying academic levels on the efficacy of online learning modalities.

The scales of evaluation proposed were the following two:

- **Scale of evaluation of academic results (teacher)**

  0 – 1 Totally negative (No results, sometimes even sort of a regression to a less advanced level of performing skills: NO pass)

  1 – 2 Very poor (Only a minimum progression, lack of organisation and many delays in bringing to conclusion the preparation of the assigned work, many mistakes in the evaluation tests, incapable to advance to next level: NO pass)

  2 – 3 Poor (Even with some progression the students show evident lack of the required skills in their advancement to next level: NOT PASSED)

  3 – 4 Sufficient (The students meet the basic requirements in their advancement to next level, yet showing some difficulty and some mistakes: PASSED 18/30)

  4 – 5 Good (successful performance of the evaluation tests with good results and only some mistakes: PASSED 24/30)

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5 – 6 Very good (Very successful performance of the evaluation tests, with almost no mistakes: PASSED 27/30)

6 – 7 Excellent (Almost perfect performance of the evaluation tests, no mistakes and exact execution of all required tasks: PASSED 30/30)

7 – 8 Exceeding expectations (Absolutely perfect performance of the evaluation tests, bringing up some very personal and interesting contribution from the students: PASSED 30/30 cum laude)

- **Scale of evaluation of appreciation feedback (students)**

0 – 1 Totally negative (I don't feel I could learn anything during the lessons, even I have the feeling I got more confused about my performing skills, I am stressed and preoccupied that I will not pass the evaluation tests)

1 – 2 Very poor (I did only very small progresses during the lessons, and I still have many doubts about my performing skills and how to get better in my singing, I am a bit preoccupied I will not pass the evaluation tests)

2 – 3 Poor (I did learn what I was expected to, but I don't feel I can really reproduce those same results on my own, I need to repeat this same lesson in order to fully understand what the teacher asks me to do, I am sure that need much more lessons in order to pass the evaluation tests, I feel rather preoccupied)

3 – 4 Sufficient (I feel I have learned something and that I can reproduce the same results on my own, yet I doubt about some details that I couldn't catch at the lesson, and I don't remember well some other parts: yet I feel quite secure about being able to pass the evaluation tests because I can count on my basic skills)

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4 – 5 Good (I feel secure and positive about what I learned today, I can reproduce the same results on my own and my performing skills are much better than last week: I get some good feeling about being able to pass my tests and I look forward to my next lessons to feel more and more secure in all my next performing events)
5 – 6 Very good (During the lesson I was able to do something that I wouldn't have been able to do on my own, I feel full of positive energy and willing to progress: I am sure I will pass my tests with a high mark; I am really looking forward to my next lessons and performing events)
6 – 7 Excellent (I am euphoric about the lesson I have just had; I did everything my teacher asked me to do and I got enthusiastic feedback from him/her: therefore, I feel that my performing skills have advanced so much in the last few months that I can expect the highest marks during the evaluations tests)
7 – 8 Exceeding expectations (This was the best lesson in my life! My teacher told me that I have reached all the planned goals and advanced even further!)

Evaluation of Lessons and Academic Performance

Throughout the duration of this study, students were tasked with evaluating the "quality" of their lessons across three distinct phases, with a particular emphasis on gauging their sense of fulfilment or frustration regarding their academic progress. To augment these student assessments, the instructor supplemented their feedback with personal observations garnered from lesson interactions and assessments conducted both prior to and during the pandemic lockdown.

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A discernible trend emerged from the comprehensive analysis of data, revealing that prior to the widespread adoption of Jamulus technology, online lessons often fell short of expectations. These sessions yielded outcomes that were deemed unsatisfactory or merely adequate when compared to previous standards of excellence. The primary contributing factor to this dissatisfaction was latency, which impeded the development of performance skills for both students and the instructor.

However, with the integration of Jamulus and other digital enhancements such as improved Wi-Fi connectivity and the utilisation of dedicated microphones and speakers, a notable transformation occurred in the quality of online instruction. The introduction of these technological tools precipitated a marked improvement in lesson quality and academic performance, effectively mirroring the standards achieved in traditional face-to-face settings. Notably, advanced students displayed a more favourable response to these technological innovations, indicating a return to pre-pandemic levels of academic engagement and achievement.

Conversely, during the initial stages of the pandemic lockdown, when online instruction relied solely on conventional methods without the aid of digital enhancements or the utilisation of Jamulus, a notable decline in both lesson quality and academic performance was observed across all student cohorts. This decline was particularly pronounced during the period of strict national lockdown, where lessons were conducted exclusively online. Academic results during this period plummeted to levels categorised as "sufficient," representing a significant departure from the previous standards of excellence. Even the most advanced students were unable to attain levels of academic excellence previously achieved.

However, with the integration of Jamulus and the gradual return to a blended learning approach combining online and in-person instruction, there was a notable resurgence in the quality of academic work, with outcomes mirroring those observed in pre-pandemic settings. This underscores the pivotal role played by technological innovations in mitigating the disruptions caused by the pandemic and facilitating a return to normalcy in academic settings.

SINGERS

The following table summarises the results of training with NMP in the context of art song classes. The table compares the perceived effectiveness of traditional and NMP based solutions to common problems in art song classes, such as phonetics and diction, interpretation of the poetic line, technical approach, musical interpretation, and performance practice.

Table 2 - Summary of results with and without NMP during pandemics.

Problems and academic skill enhancement	**Traditional solution (before pandemic emergency)**	**Networked tech enhancement (to cope with the digital lessons problems)**	**Tools**

Phonetics and diction	Study of articulation and pronunciation exercises with a detailed approach, with explanations and direct showing by the teacher: the pupil tries to imitate, and the teacher makes corrections. Rhythmic reading of the texts following the structure of the melody.	Slides with theoretical explanation (intense use of the IPA International Phonetic Alphabet). Audio recorded demos by the teacher with high quality sound. Demos of the student's exercises to be analysed and verified by the teacher. Video conference as a group or 1-to-1 lesson. Files audio with text recitation produced by the pupils and corrected by the teacher.	PowerPoint or similar/Pdf or similar. Audio and video recording devices (high quality) with good microphones. PC/Laptop/Notebook/iPad/ etc. with applications for video conferences (such as Zoom, Google Meets, Teams, Skype, etc.).
Interpretation of the poetic line	Translation and explication of text, with reference to styles, historical period analysis and resume of	Slides with theoretical explanation (intense use of the IPA International Phonetic Alphabet). Audio recorded demos by the	PowerPoint or similar/Pdf or similar. Audio and video recording devices (high quality) with good

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	biography of the author. Lecture and question answering.	teacher with high quality sound. Demos of the student's exercises to be analysed and verified by the teacher. Video conference as a group or 1-to-1 lesson. Files audio with text recitation produced by the pupils and corrected by the teacher with notes and suggestions.	microphones. PC/Laptop/Notebook/iPad/ etc. with applications for video conferences (such as Zoom, Google Meets, Teams, Skype, etc.).
Technical approach (vocal technique, body posture)	Technical exercises through vocalisation, hints for vocal warming up, explanations and examples by the teacher. In presence the possibility of a direct	Without the possibility of the direct interaction between teacher and the pupil's body, the same work online, by also using videos and pictures downloaded from the internet. The teacher shows on video some ways to verify the correct	PowerPoint or similar/Pdf or similar. Audio and video recording devices (high quality) with good microphones. PC/Laptop/Notebook/iPad/ etc. with applications for video

	interaction with the teacher on posture and movements, verification of the correct interpretation of the exercises on the pupil's body.	interpretation of the technical exercises and body posture. Group lessons on the general technical methods on breathing, sound placement and vocal articulation.	conferences (such as Zoom, Google Meets, Teams, Skype, etc.) At this stage the use of Jamulus improved the quality of the interaction on the sound production and allowed the group work on some specific exercises.
Musical interpretation (words combined to music, style praxis and score analysis)	Score analysis by reading through it and pointing out the main musical characteristics: rhythmical and harmonical design, structure and musical form, melodic phrasing, connection between music and	Slides of a presentation with the score analysis to be used during the online lecture. Audio recorded demos by the teacher with high quality sound. Demos of the student's exercises to be analysed and verified by the teacher. Video conference as a group	PowerPoint or similar/Pdf or similar. Audio and video recording devices (high quality) with good microphones. PC/Laptop/Notebook/iPad/ etc. with applications for video conferences (such as Zoom, Google Meets, Teams, Skype,

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	poetry.	lesson to share with other students the results and the methods. Listening to great performers and analysing their interpretation.	etc.).
Performance practice and memorization skills	In presence exercises of performance in front of the teacher and *with the assistance of a professional accompanist* (vocal coach). Possibility to alternate 1-to-1 lessons with a small group masterclass with other students, in order to reproduce the real	Online ● 1st stage – The student sings "a cappella" the vocal line and the teacher makes all the necessary corrections. ● 2nd stage – The student sings on a *pre-recorded base* and tries to perform the piece. ● 3rd stage – Whenever possible, the singer performs with an accompanist, if available (main problem: latency of the sound when the accompanist	Audio and video recording devices (high quality) with good microphones. PC/Laptop/Notebook/iPad/ etc. with applications for video conferences (such as Zoom, Google Meets, Teams, Skype, etc.). An extensive use of the application Jamulus that allows the ensemble work by minimising the latency with the accompanist.

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	"performing" situation energy.	isn't in the same room as the singer). ● 4th stage – Production of high-quality videos to be evaluated by the teacher.	

1.3.2 Professional Training: Case Study of Ensemble Lira Transalpina

In the genesis of the IMSV project, the ensemble Lira Transalpina[15] embarked on a pioneering journey into the realm of Networked Music Performance using Jamulus. This groundbreaking initiative marked a significant milestone in the project's inception, as the ensemble endeavoured to navigate the challenges posed by geographical dispersion amidst the global pandemic.

Comprising four musicians situated across Italy, Switzerland, and France, Lira Transalpina epitomised the spirit of collaboration and innovation inherent in the IMSV project. Driven by a shared passion for chamber music spanning diverse genres, ranging from historically informed

[15] https://liratransalpina.altervista.org/

compositions to contemporary popular tunes, the ensemble seized the opportunity to harness NMP technology to sustain their musical endeavours in the face of unprecedented adversity.

The decision to adopt Jamulus as the primary NMP tool stemmed from a meticulous evaluation of available options and a commitment to accessibility and inclusivity. Although inspired by the pioneering LoLa system developed by the Conservatorio di Musica G. Tartini of Trieste, Jamulus does not share its prohibitive cost that makes it impractical for individual users (such as Lira Transalpina). In contrast, Jamulus, with its open-source framework and user-friendly interface, emerged as an ideal solution, offering a balance between quality and affordability.

As the ensemble delved into their inaugural NMP endeavours, they encountered a multitude of technical challenges inherent in remote collaboration. Chief among these challenges was latency, the time delay incurred in transmitting audio streams over the internet, which posed significant hurdles to real-time musical interaction. While minor delays of up to approximately 40 milliseconds could be perceived as synchronous, longer delays rendered live collaboration virtually impossible.

Furthermore, the phenomenon of jitter, characterised by fluctuations in packet delay over time, compounded the ensemble's technical struggles, resulting in choppy or distorted sound quality. The potential for packet loss further exacerbated these issues, manifesting as intermittent audio "blackouts" during performances.

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To address these challenges, the ensemble diligently experimented with delay buffers and jitter buffers integrated within Jamulus. However, striking a delicate balance between buffering and overall round-trip delay proved to be a complex endeavour, requiring meticulous fine-tuning to optimise performance quality without compromising real-time interaction.

Despite these technical hurdles, Lira Transalpina remained steadfast in their commitment to leveraging NMP technology to redefine the boundaries of remote musical collaboration. Through perseverance, innovation, and a shared dedication to their craft, the ensemble embarked on a transformative journey that exemplified the resilience and adaptability of artists in the face of adversity.

Preliminary Tests of Jamulus: Installation and Configuration

Before delving into the realm of Networked Music Performance on Jamulus, it is imperative to undertake a phase of familiarisation and configuration. Understanding the fundamental settings is paramount to mitigate potential issues such as echoes and disruptions during sessions.

To address latency issues inherent in online collaboration, it is essential to utilise ASIO4ALL and select a server that minimises time lag for all participants. Achieving a low ping, ideally below 25 milliseconds, is crucial for ensuring smooth and synchronous communication among ensemble members. Ping, measured in milliseconds, represents the round-trip duration between the host connection point in Jamulus and the server where participants connect. The lower the ping, the more efficient and reliable the connection becomes.

Description of a Working Session

Ensemble Lira Transalpina conducted rehearsals using Jamulus, connecting to the "DPKprod" server located in Saint Marcellin, a French commune. The ensemble members were dispersed across various locations, with distances ranging from 90 kilometres (between Saint Marcellin and Lyon) to 390 kilometres (between Saint Marcellin and Milan).

This geographical dispersion posed a challenge that was effectively addressed by selecting a server strategically positioned to minimise latency for all participants. By leveraging Jamulus's capabilities and optimising server selection, the ensemble achieved seamless collaboration despite the physical distances separating them.

Through meticulous planning and effective utilisation of available tools, Lira Transalpina demonstrated the viability and effectiveness of Jamulus as a platform for remote musical collaboration. This successful working session serves as a testament to the adaptability and resilience of musicians in harnessing technology to overcome geographical barriers and pursue artistic endeavours collectively.

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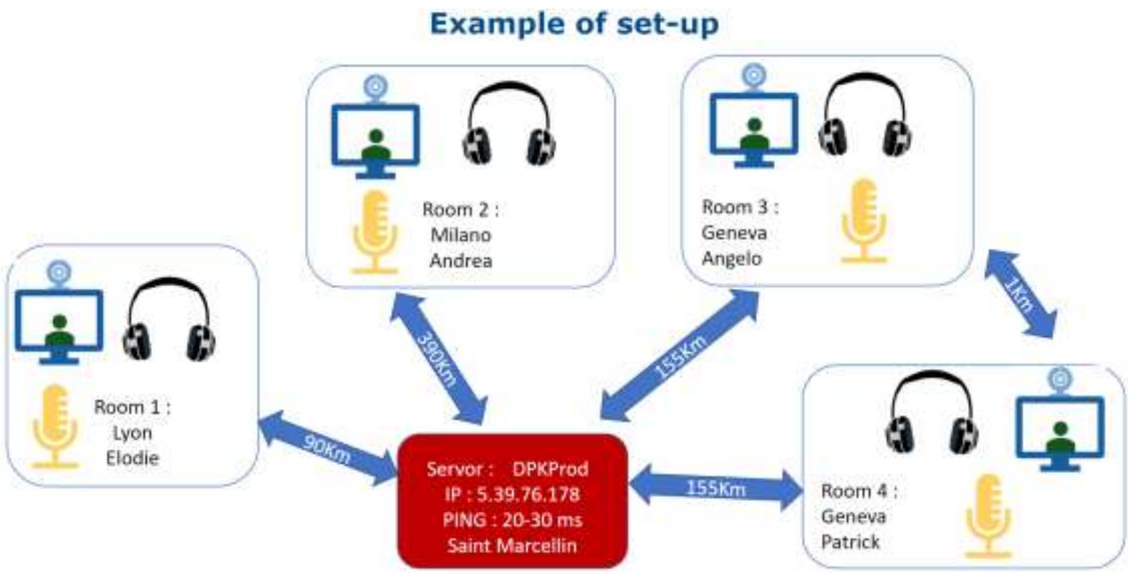

Figure 30 - The NMP session with Jamulus by the four musicians of Lira Transalpina.

Enhancing Remote Rehearsals with Jamulus: A Comprehensive Overview

In the transition to remote rehearsals facilitated by Jamulus, each musician equips him/herself with essential tools to facilitate seamless communication and collaboration. Armed with a computer equipped with either an integrated or external microphone, as well as a headset (sans microphone), and a webcam for supplementary visual interaction via platforms like Zoom, ensemble members are prepared to navigate the nuances of virtual music-making.

Video Demonstration: Networked Music Performance for Baroque Music with Jamulus

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A tangible illustration of the ensemble's adaptation to remote collaboration is showcased in the video titled "Networked Music Performance for Baroque Music with Jamulus".[16] This video exemplifies the ensemble's adeptness in leveraging technology to overcome geographical barriers and maintain musical cohesion amidst the challenges posed by the pandemic. The second video shows the use of Jamulus in the context of vocal training. M° De Lisi outlines the advantages and the challenges of NMP in the pedagogical training for vocal chamber music.

Navigating Phased Restrictions

Throughout the pandemic, Ensemble Lira Transalpina was one of the first music groups to use the NMP technique. The ensemble encountered different degrees of restrictions dictated by the prevailing circumstances in each respective country, ranging from partial lockdowns to complete confinement. In response, the frequency of rehearsals fluctuated accordingly, with the ensemble convening anywhere from one to two times per week during periods of strict containment, tapering to once every two to three weeks as restrictions eased. The use of NMP technique requires a certain training in order to be effective. The ensemble witnesses multiple phases of this training:

Phase 1 - Acclimating to Jamulus

[16] https://www.youtube.com/watch?v=eUIQULPVM8s https://youtu.be/3c75J6y-7V4

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The initial phase of transitioning to Jamulus spanned approximately three to four rehearsals, during which each member grappled with the technical intricacies inherent in remote collaboration. This acclimatisation period was characterised by a learning curve as musicians familiarised themselves with connectivity issues, sound quality discrepancies, and audio latency. Key observations during this phase included:

- **Disparity in rehearsal experience** – A discernible contrast emerged between traditional in-person rehearsals and remote counterparts, necessitating an adjustment period for ensemble members.
- **Echo and audio delay –** The introduction of a slight delay in hearing one's own sound through the headphones, colloquially referred to as an "echo," initially disrupted musical practice. Over time, musicians adapted their listening approach to synchronise with the delayed audio feedback from Jamulus, enabling cohesive ensemble performance.
- **Mitigating the absence of eye contact –** The absence of visual cues inherent in Jamulus sessions posed challenges in spatial perception and communication. To mitigate this, the ensemble adopted supplementary video conferencing tools like Zoom, albeit with occasional synchronisation issues between audio and video. Despite these challenges, video conferencing aided in bridging the gap created by the absence of physical proximity, facilitating a more immersive rehearsal experience.

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As ensemble members progressively acclimated to the nuances of remote collaboration, the reliance on supplementary video conferencing tools diminished, giving way to a heightened auditory sensitivity and adaptability conducive to effective remote rehearsals.

Phase 2 - Mastery Jamulus

Following the initial adjustment phase, ensemble members embarked on a journey of mastery and integration with Jamulus, transcending the challenges of remote rehearsal through resilience and adaptability. As musicians delved deeper into this novel rehearsal format, they not only embraced its benefits but also evolved both individually and collectively, pushing the boundaries of their musical proficiency.

This transformative phase heralded a multifaceted cognitive evolution, marked by heightened auditory acuity, refined interpretative sensibilities, and a deeper appreciation of chamber music dynamics. Musicians refined their listening skills, developing a heightened sensitivity to subtle nuances in sound and rhythm. Their approach to interpretation became more nuanced, with a focus on unravelling the underlying musical narrative while elucidating intricacies in phrasing and expression.

Furthermore, the ability to anticipate tempos emerged as a pivotal skill, facilitated by the immersive nature of remote collaboration. Overcoming the challenges posed by latency and audio delay,

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ensemble members cultivated a keen sense of rhythmic anticipation, enabling seamless synchronisation and cohesion in performance.

As the constraints of confinement gradually eased, the transition back to face-to-face rehearsals was facilitated by the proficiency acquired through remote collaboration. With newfound agility and precision, rehearsals regained their fluidity, allowing musicians to delve into intricate details of interpretation with ease and efficiency.

Addressing Technical Challenges: Proposed Solutions

Considering the experience of Lira Transalpina, the authors of IMSV recommend some hints for solving common problems. The official website of Jamulus[17] offers a more comprehensive (and long) description of the problems you may encounter in the making of NMP rehearsals.

- **Install ASIO drivers (Win only)** - If you are a Windows user, you need to install ASIO drivers. If you are using an external soundboard, you may use the ASIO driver of your device. If you are not using a soundboard, you may download and install ASIO4all drivers[18].
- **Use headphones** - The use of wired headphones is necessary for NMP. Listen to the signal coming from the distant server, not the sound you're producing in your own room. This can

[17] https://jamulus.io/wiki/Client-Troubleshooting
[18] https://asio4all.org/about/download-asio4all/

be perceived like an echo, but this is normal: if you perceive an echo in your own signal, it means that the NMP is working.

- **Internet connection quality –** The efficacy of online rehearsals hinges on the quality of the internet connection. Fibre optic networks offer superior performance compared to ADSL counterparts, ensuring stability and reduced latency. Wired connections further enhance reliability, mitigating potential disruptions during sessions.
- **Server selection –** Optimal server selection is paramount to minimise ping and delay, ensuring equitable participation for all ensemble members. Proximity to the server is crucial, with each participant ideally connected to a server that facilitates low-latency communication.
- **Audio issues** – Latency and distortion present significant challenges during remote rehearsals, necessitating innovative strategies to maintain synchronicity and cohesion. Ensemble members experimented with anticipatory techniques, pre-emptively aligning their rhythms to mitigate perceptible slowdowns induced by audio delay. Additionally, designating a musical leader to anchor tempo enhanced ensemble cohesion, complementing individual efforts to maintain rhythmic precision.

By proactively addressing these technical challenges and embracing innovative solutions, ensemble members navigated the intricacies of remote collaboration with resilience and creativity. This collective journey of adaptation and growth underscores the transformative potential of technology in redefining traditional paradigms of musical collaboration, paving the way for a harmonious and productive rehearsal environment characterised by synergy and artistic excellence.

1.3.3 Distant Learning Setup: Recording an NMP Session with Video

In this section, we delineate procedures for conducting an NMP session, considering both video and audio components. The choice between utilising video or solely audio depends on network quality, with the option to incorporate sampled instruments into Jamulus. The following outlines the procedural steps for initiating sessions with virtual instruments and NMP, as well as incorporating sampled instruments.

Procedure for Opening an NMP Session with Virtual Instruments

1. Begin by launching Jamulus, the platform facilitating real-time audio communication.
2. Open Reaper, a Digital Audio Workstation utilising the Jamulus2Reaper[19] template by Cavina and Bareggi.
3. Connect to a designated server to establish network connectivity.
4. If opting for video integration, launch Zoom and establish connections with session partners. Notably, due to the use of ASIO (Audio Stream Input/Output) by both Reaper and Jamulus, sound devices will not function with Zoom.

[19] https://www.mediafire.com/file/vbe70le8eu8z26e/templateReaper2Jamulus.rpp/file

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Procedure for Opening an NMP Session with Sampled Instruments

1. Initiate MIDI sampler software, such as Kontakt, and ensure connectivity with a MIDI keyboard for instrument control.
2. Load the desired MIDI instrument into Kontakt, configuring settings as necessary (e.g., selecting the harpsichord Blanchet 1720).
3. Configure ASIO output settings to ensure proper audio playback through speakers.
4. Launch Jamulus to initiate real-time audio communication.
5. Open the Digital Audio Workstation, utilising Reaper with the ReaRoute template for audio routing.
6. Connect to the designated server to establish network connectivity and commence the NMP session.

Ensemble Lira Transalpina has tested the use of VSTi via MIDI input with the DAW Reaper during a NMP test. In this case Andrea Bareggi was connected from Neuville sur Saone and playing the VSTi harpsichord[20] on a MIDI keyboard activated by the Jamulus2Reaper[21] template.

Table 3 - Network data for the rehearsal of instrumental parts of Aquilon et Orithie by Rameau.

Musician	Location	Network	Download	Upload	Jamulus	Overall	Network

[20] http://sonimusicae.free.fr/blanchet1-en.html
[21] https://www.mediafire.com/file/vbe70le8eu8z26e/templateReaper2Jamulus.rpp/file

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		Ping	**speed**	**speed**	**Ping**	**delay**	**quality**
Evan Buttar	Den Haag (NL)	9 ms	71 Mbps	28 Mbps	15 ms	33 ms	Medium
Elodie Colombier	Lyon (FR)	5 ms	398 Mbps	274 Mbps	15 ms	46 ms	Excellent
Andrea Bareggi	Neuville sur Saone (FR)	10 ms	42 Mbps	61 Mbps	15 ms	50 ms	Medium

Procedure for NMP Session with Android and iOS devices

The procedure for using Jamulus with Android and iOS mobile devices is simpler than using the same technique with computers. However, the authors point out that mobile devices offer a mediocre quality compared to computers. In order to use Jamulus on mobile devices, you have to download and install the APK file for Android[22] or visit the Apple Store[23] to download the Jamulus app.

[22] https://www.mediafire.com/file/4duu8k5081dcmcn/Jamulus_3.8.1_android.apk/file you have to authorise the installation on your device
[23] https://apps.apple.com/is/app/jamulus2-0/id1609844773

By adhering to these procedural guidelines, participants can effectively conduct NMP sessions, leveraging both virtual and sampled instruments to facilitate immersive musical collaboration. These steps ensure seamless integration of audio and, if applicable, video components, fostering a conducive environment for remote musical interactions.

Part 2 - Audio Tools (Hardware and Software) for Music Recording and Editing (PPB)

This section outlines the hardware and software requirements essential for ensuring high-quality audio in distance or blended learning sessions. We will explore how technological tools can be seamlessly integrated into traditional in-person sessions, enriching the ensemble music experience and opening new frontiers in music education. A detailed list of hardware requirements will be provided, categorised by levels of accessibility. This approach allows institutions to offer the best possible audio experience, enables faculty to achieve consistent results both in academic settings and remotely from their personal workstations, and ensures students can participate effectively without needing to invest in expensive equipment.

Following these guidelines, students will be able to employ these new methodologies using their smartphones, tablets, and PCs. The necessary tools will include headphones or headsets and free software integration, with the only additional requirement being an external microphone.

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In this section, we will thoroughly analyse and propose the essential requirements for the effective remote practice of chamber music. Active listening is a fundamental objective in this type of ensemble, and to support this, we will review various hardware and software options available on the market. This will include a comprehensive overview of the primary techniques for live sound collection and recommendations on microphone placement. The goal is to ensure that the sound quality is as authentic and true to the live experience as possible.

Currently, several conservatories possess some recording resources, such as the Conservatorio Superior de Música de Coruña. However, a significant issue is that many educators lack the necessary training to utilise these resources effectively, and our administration does not provide a sound technician. Therefore, one of the key objectives of this section is to fill this gap by offering basic guidelines on the correct use of these resources.

By understanding and applying these hardware and software requirements, both educators and students can significantly enhance their remote and blended music sessions. This approach not only improves the quality of audio but also fosters a more engaging and authentic ensemble music experience. Ultimately, this section aims to equip music educators and students with the knowledge and tools needed to navigate and excel in the evolving landscape of music education.

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2.1 Required Hardware Equipment

To maximise the potential of each rehearsal or teaching session via IMSV, every user must have a specific set of equipment. This setup enables teachers and students to play and communicate over long distances with the best possible sound quality. Ensuring high standards of digital sound will ultimately enhance the experience for all users, contributing to a more realistic musical experience and yielding positive pedagogical and artistic results.

Given that each user will be alone in a room with his or her instrument, communicating with other musicians or students in similar isolated conditions, it is crucial to select equipment that supports high-quality online sound transmission for a single instrument played by one performer. This scenario necessitates a set of essential devices that enable a single performer to play, interact, and communicate musically in an online environment.

The essential equipment includes a reliable external microphone, which captures the instrument's sound with high fidelity, and quality headphones or headsets, which provide clear audio output and enable precise listening. Additionally, a stable internet connection is vital to minimise latency and ensure smooth, real-time communication. A computer or mobile device capable of running the necessary software applications is also required. These software applications should support high-quality audio transmission and allow for seamless integration with the hardware.

Moreover, an audio interface can significantly enhance the sound quality by providing better input and output options compared to the built-in audio systems of most computers and mobile devices. This ensures that the sound captured by the microphone is transmitted with minimal loss of quality.

By following the suggestions provided in the handbook of IMSV, the users are guided in choosing the best hardware and software configuration for effective and immersive online music sessions, ensuring that both teachers and students can achieve the highest possible sound quality and maintain the integrity of their musical interactions.

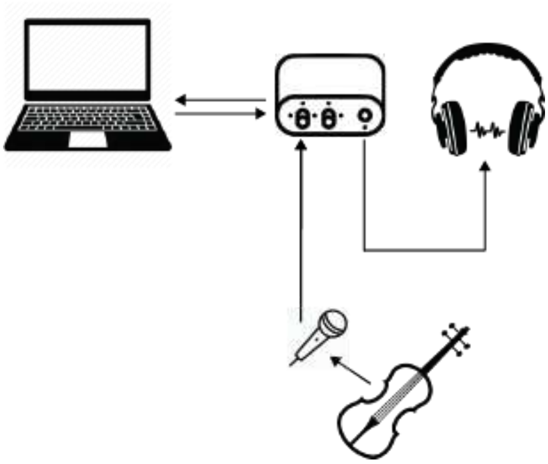

Figure 31 - Diagram explaining the use of USB sound card: the card manage inputs (such as microphone and MIDI interfaces) and outputs (such as headphones and speakers).

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2.1.1 Computer

The computer is undoubtedly the central component of this setup, facilitating online connections with other teachers, students, and musicians via Jamulus, as well as enabling various solutions for playback and audio editing using REAPER. It serves as the primary platform for audio signals, allowing performers to input their instrument sounds and output the sounds of other performers connected simultaneously through Jamulus. The required software is compatible with macOS, Windows, and Linux, providing a wide range of choices for computer purchases. When selecting a computer, it is important to consider its processing power, memory, and storage capacity to ensure smooth operation of audio applications and real-time communication.

2.1.2 Audio Interface

An audio interface is essential for inputting and outputting audio to and from the computer. This device connects to the computer, typically via USB or USB-C, and allows users to connect one or more microphones, converting the acoustic sound into a digital signal. This conversion enables the sound to be utilised in various ways, from live-online sessions to simply recording the instrument signal on a Digital Audio Workstation. The audio interface also enables users to listen to the computer's output audio signal from a live session in Jamulus or playback a recording made by the performer on a DAW.

When choosing an audio interface, it is crucial to select one with at least one XLR input with 48V phantom power. This feature is necessary for using condenser microphones, which are described in detail below. Additionally, the audio interface should have a headphone output for audio monitoring, ensuring that the user can accurately hear the sound being captured and transmitted.

2.1.3 Microphones

The microphone serves as the direct link between the instrument's sound and other users in the same online session. It captures the sound and sends it to the computer software via the audio interface. There are several types of microphones available, each suited to different acoustic and musical contexts, resulting in varying sound characteristics. For capturing acoustic instruments for online transmission, a condenser microphone is the most versatile choice.

Condenser microphones are known for their superior sound quality due to their extremely low-mass diaphragm, which can accurately follow sound waves more precisely than a dynamic microphone's heavier moving coil. This characteristic also results in higher sensitivity, allowing better audio capture from greater distances, which can be beneficial in various situations.

For string and wind instruments, a single condenser microphone is often sufficient to capture the sound accurately. However, for piano and percussion setups, including keyboard percussion instruments, it is advisable to use two microphones for better audio capturing. This is because these instruments have a larger resonance surface, which requires more coverage to capture the full range of sound.

When setting up microphones, it is essential to consider their placement to achieve the best sound quality. For string instruments, positioning the microphone close to the sound source can capture the nuances of the performance. For wind instruments, placing the microphone slightly off-axis can prevent excessive breath noise. For pianos, positioning two microphones, one near the low strings and one near the high strings, can provide a balanced and rich sound capture. Similarly, for percussion instruments, placing microphones strategically around the instrument can ensure all elements of the sound are captured accurately.

In conclusion, the combination of a well-chosen computer, a reliable audio interface, and high-quality microphones is crucial for maximising the potential of online music sessions. By ensuring each component is selected and set up correctly, teachers and students can achieve high-fidelity sound transmission, enhancing their musical interactions and overall learning experience.

2.1.4 MIDI Instruments

The use of MIDI instruments, while optional, can be advantageous in two significant ways:

1. **For piano players** – A MIDI keyboard can serve as a substitute for traditional pianos, eliminating the need for microphones to capture the piano sound. In this scenario, the sound

is digitally generated and directly sent from the sampler software to Jamulus or REAPER. This method ensures high-quality sound transmission without the complications of acoustic capture.

2. **For teaching and rehearsal sessions –** A MIDI keyboard is a practical tool for demonstrating musical examples quickly and efficiently, much like a piano in a traditional classroom setting. This allows teachers to illustrate concepts and provide examples seamlessly during online sessions.

Other MIDI instruments, such as MIDI drums or MIDI drum pads for percussionists and wind MIDI instruments like the AKAI Professional EWI 5000 for wind players, can also be connected to various virtual instruments. These instruments can be effectively used in several online contexts, offering versatility and enhancing the teaching and learning experience.

2.1.5 Headphones

Headphones are crucial for online sessions and recording. They allow the user to listen to other performers and their instrument signal, ensuring clear communication and coordination. Moreover, headphones are essential for preventing feedback, which can disrupt online sessions.

The most effective types of headphones for this purpose are in-ear buds or closed-back headphones, as they completely prevent feedback. Closed-back headphones provide excellent isolation, ensuring

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that no sound leaks into the microphone, which is crucial for maintaining sound quality in an online setting.

On the other hand, open-back headphones allow performers to have better direct acoustic monitoring of their instrument, creating a more natural musical experience. However, when using open-back headphones, it is crucial to carefully adjust the output volume to prevent feedback, as sound leakage can occur.

2.1.6 Cables, Connectors, and Mic Stands

To connect the entire set of equipment described, the following accessories are necessary:

- **XLR Cable** – This cable is used to connect the microphone to the audio interface, ensuring a secure and high-quality signal transmission.
- **Microphone stand –** A microphone stand is essential for positioning the microphone optimally in relation to the instrument's sound projection. Proper placement is key to capturing the best possible sound.
- **Converter** – A converter from a mini-jack (3.5 mm female) to a jack (6.3 mm male) is often required, as most headphones use a mini-jack connector. This converter allows the headphones to plug into the 6.3 mm jack audio interface headphone output, ensuring compatibility and functionality.

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2.1.7 Additional Considerations

When setting up MIDI instruments, it is crucial to ensure that the software used is compatible with the hardware and offers the necessary features for the intended use. For example, piano sampler software should provide high-quality sound libraries that accurately replicate the nuances of an acoustic instrument. This ensures that the digital instrument sounds as close to the real thing as possible, enhancing the overall musical experience.

Comfort is also an important factor to consider when selecting headphones, especially for long sessions. Headphones should deliver good sound quality while being comfortable to wear for extended periods. This can help prevent fatigue and ensure that users can focus on their music without discomfort.

Cables and connectors should be of high quality to ensure reliable connections and minimise signal loss. Investing in durable and well-made accessories can prevent technical issues during critical sessions. High-quality cables and connectors not only provide better sound quality but also reduce the likelihood of interruptions caused by faulty connections.

In conclusion, incorporating MIDI instruments, selecting appropriate headphones, and using the right accessories can significantly enhance the effectiveness of online music sessions. These components work together to ensure high-quality sound transmission, improve the overall musical experience, and facilitate seamless teaching and learning interactions.

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2.1.8 Suggestion for Equipment Setup

Acquiring a set of equipment for online training and teaching sessions can vary in cost depending on the quality of the hardware and its inherent prices. Therefore, it is necessary to find a decent set of equipment that corresponds to personal economic possibilities while still ensuring the quality of the acquired devices and their subsequent audio results. Considering this economic factor, some suggestions can be made, divided into three groups:

1. **Institutions –** Typically, institutions such as schools and universities have larger budgets for equipment purchases. Therefore, the suggested equipment for this group is top quality and inherently more expensive. This ensures that the institution can provide the best possible audio experience for all users.

2. **Teachers –** The suggestion for teachers is affordable and falls within a mid-range price. This setup balances cost and quality, providing reliable performance without requiring a significant investment.

3. **Students –** The suggestion for students is in the low-price range but still ensures the necessary quality standards for online sessions, recording, audio editing, and playback activities. This setup makes it accessible for students to participate effectively without a heavy financial burden.

Considering that any new computer can connect to the internet and run the required software, the next three groups of equipment setup suggestions will focus only on the audio interface and microphones. MIDI instruments are optional, and all necessary accessories (cables, connectors, and mic stands) are essentially the same for all three groups and do not significantly impact sound quality.

Institutions:

- **Audio Interface:** High-end models like the Focusrite Scarlett 18i20, the Universal Audio Apollo Twin or Motu UltraLite mk5 USB-C audio interface
- **Microphones:** Top-tier options like the Neumann TLM 103 for exceptional sound quality or Neumann KM183 Stereo pair

Teachers:

- **Audio Interface:** Mid-range models like the Focusrite Scarlett 2i2, Focusrite Scarlett 3rd Gen 8i6, the PreSonus AudioBox USB 96 or Zoom U-24.
- **Microphones:** Reliable options such as the Audio-Technica AT2020, the Rode NT1-A or Rode M5 condenser microphone pair

Students:

- **Audio Interface:** Budget-friendly models like the Behringer UMC22, the M-Audio M-Track Solo, or Behringer U-Phoria UMC22
- **Microphones:** Cost-effective choices like the Samson C01, the Audio-Technica ATR2500x-USB or the t.bone EM 700

By selecting the appropriate equipment based on budget and quality needs, users can ensure high-quality audio transmission and enhance their online music sessions. This approach enables institutions, teachers, and students to achieve their musical and educational goals effectively.

2.2 Required Software Equipment

We have divided the software into two categories, which include different musical contexts: live sessions, and audio recording, playback, and editing. These software applications can be installed on macOS, Windows, and Linux.

Live Online Sessions: Jamulus

Jamulus is a software developed for playing, rehearsing, and jamming with other users online. It is specifically designed and programmed to host a private server, offering high-quality and low-latency sound. This enables musical performance between two or more musicians in an online environment, making it ideal for live sessions. Jamulus is optimised to reduce latency, which is crucial for synchronous playing, ensuring that musicians can interact in real-time with minimal delay. This

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software is particularly beneficial for ensemble practices, remote rehearsals, and collaborative performances, as it creates a virtual space where musicians can play together as if they were in the same room.

Audio Recording, Playback, and Editing: REAPER

REAPER is a Digital Audio Workstation (DAW) that offers a comprehensive multitrack audio and MIDI recording, editing, processing, mixing, and mastering toolset. REAPER supports a vast range of hardware, digital formats, and plugins, and it can be extensively extended, scripted, and modified to suit various needs.

REAPER is known for its intuitive interface, which allows users with minimal experience to quickly become proficient. This makes it an excellent choice for the IMVS project, where a straightforward recording and editing process is essential. The software provides all the necessary features without requiring a lengthy training period, making it accessible for both teachers and students. Additionally, REAPER allows for simple audio processing, such as adjusting the speed of a track. This feature is particularly useful for training and teaching, as it enables playback at different speeds, helping students to learn and practise more effectively.

By utilising these software tools, users can achieve high-quality live sessions and efficient audio recording, playback, and editing. Jamulus and REAPER together provide a robust solution for the

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varied needs of online music education, ensuring seamless integration and a user-friendly experience across different operating systems.

One of the objectives in the practice of chamber music is to establish a real musical dialogue, and for this, beyond being able to play in tempo (an issue that is constantly being improved thanks to the progress of technology) it is necessary to experiment with the different qualities of sound: colour, articulation, intensity, duration and frequency.

Simple Tutorial for tempo changing of a PPB track in Reaper

This short tutorial will allow you to locally change the tempo of an audio file (for example, if you want to slow down a cadenza).

1. Measure the metronome of your track and set it to Reaper (see Figure, Tempo at edit cursor).

Figure 32 -The cursor in the track of Reaper.

2. Import a track (just drag and drop an audio file in a black space).

Figure 33 - The track panel in Reaper.

3. Disable Snap (Alt+S) for allow selection between two beats.
4. Go to the point for tempo changing.
5. Cut the part of the track for tempo changing. Press S for cutting.
6. Drag on the right side the right part of the track you do not want to modify.
7. Select the part of the track you want to modify.

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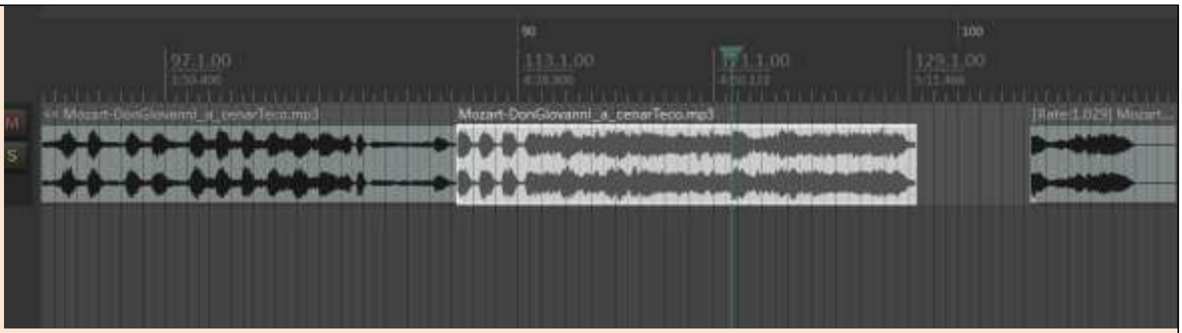

Figure 34 - The cursor is positioned on the track, ready for separating the cadenza we want to slow down.

8. Press and keep ALT for obtaining the hand tool. This tool is visible only if your mouse is on the boundary of the selected track.
9. With this tool, drag the part to be modified (on the right for slowing down, on the left to speed up the tempo). Be careful! avoid tempo changes that exceed 15% in order to avoid unwanted audio artefacts. In this example the track has been slowed down with a ratio of 0.90 (so 10% change).

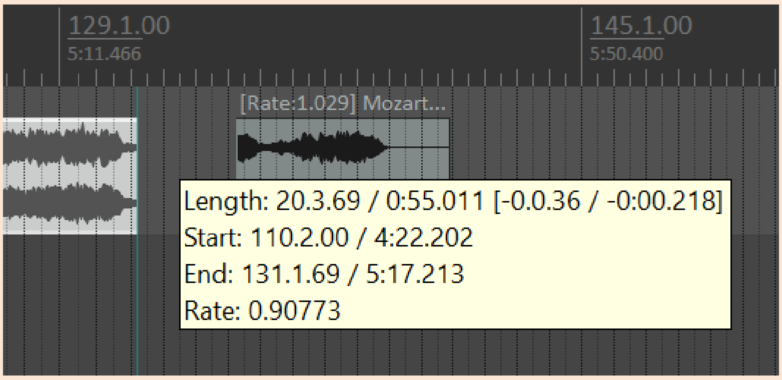

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Figure 35 - The cadenza has been slowed down and now it should be reconnected to the previous part.

10. drag the right part of the track in order to overlap the interface.

Figure 36 - After zooming in, the two parts are merged together with a mutual fade out, visible in red lines on the figure.

Beware, The zoom level is very high in this screenshot!

2.3 Stereo Live Sound Recording Techniques

Since in section 2.2 we focused on the different possibilities to collect sound through hardware and software, section 2.3 will focus on three fundamental aspects: the technique for sound recording, the placement of the microphones and possible peculiarities of each instrument. In the practice of chamber music, establishing a genuine musical dialogue is a primary objective. Beyond playing in tempo, which is increasingly achievable with advancements in technology, exploring the diverse qualities of sound is essential. These qualities include colour, articulation, intensity, duration, and frequency.

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In chamber music, stereo sound recording is vital for capturing an organic sound quality. This approach enhances the sound of instruments and captures the diverse dynamics and nuances of the piece, allowing performers to refine tempo and sound qualities effectively.

2.3.1 Matching Techniques for Sound Recording

XY Technique

This method employs two cardioid microphones positioned at a 90º angle between their axes. The Rode M5 microphone is a recommended option for this technique. When placed at a considerable distance, there may be a loss of low-frequency information. The stereo image produced by this technique is typically not very wide. Ideally, the microphones should be positioned approximately 3.5 metres from the ensemble. The microphone's height should be around 1.8 metres to capture the sound accurately.

The XY technique offers a balanced stereo image and is suitable for capturing the nuanced interactions between instruments in chamber music performances. While it may not provide the widest stereo spread, it excels in capturing detailed sound quality, making it a preferred choice for recording ensembles in intimate settings.

By employing stereo recording techniques like XY, performers can capture the full richness and depth of chamber music performances, allowing for a more immersive and authentic listening

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experience. Proper microphone placement and technique are crucial for achieving optimal results in capturing the nuances and subtleties of live performances.

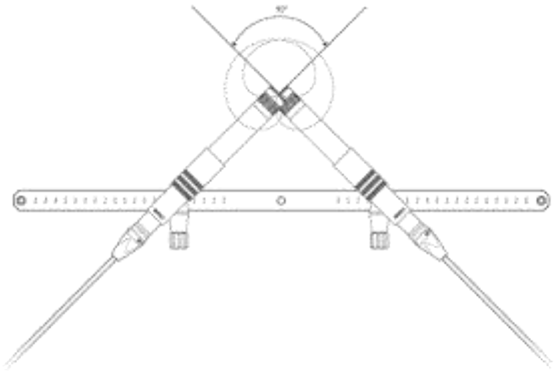

Figure 37 - XY technique (DPA Microphones, 2015).

2.3.2 Alternate Matching Techniques

NOS Technique

The NOS technique, named after the Nederlandse Omroep Stichting (Dutch Broadcasting Foundation), utilises two cardioid microphones positioned with a 90º angle between them and a diaphragm separation of 30cm. This setup results in a stereo image wider than that achieved with the XY technique, mainly due to the increased separation between the microphones. However, it's crucial to consider the proximity effect of the microphones, especially when recording at greater distances. For optimal results when capturing chamber groups, the microphones should typically be positioned between 1.8 and 3 metres away from the ensemble, adjusting the placement based on the instrument being recorded to achieve the desired sound balance and spatial representation.

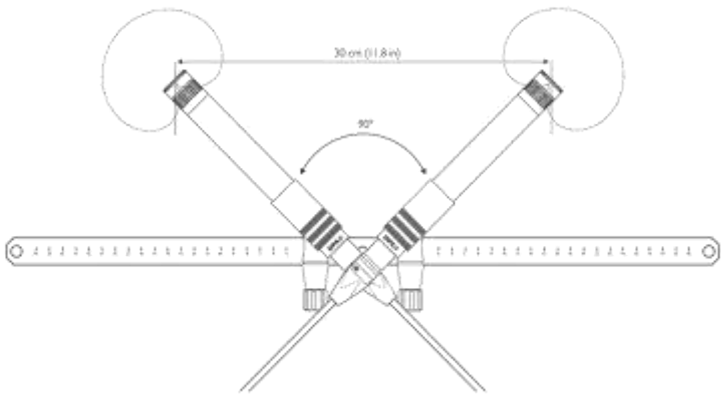

Figure 38 - NOS technique (DPA Microphones, 2016).

<u>ORTF Technique</u>

The ORTF technique, named after its inventors, the Office de Radiodiffusion Télévision Française, employs two cardioid microphones positioned with an angle of 110º and a diaphragm separation of 17 cm. These parameters are designed to replicate the natural position of human ears, capturing sound in a manner similar to how our bodies perceive it. While the stereo width achieved with the ORTF technique is slightly narrower compared to the NOS technique, it is preferred for orchestral recordings due to its ability to accurately capture the precise placement of instruments. As a general guideline for recording ensembles, the microphones should be positioned between 1.8 and 3 metres away from the group, with adjustments made based on the specific instrument being recorded.

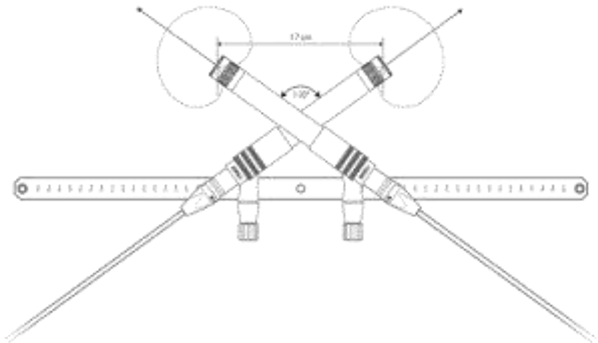

Figure 39 - ORTF technique (DPA Microphones, 2016).

Spaced Pair Technique: AB

The Spaced Pair Technique, also known as the AB technique, involves positioning two individual microphones at a distance that typically ranges between 40 and 60 cm. The separation between the microphones is determined by the wavelength of the lowest frequency, as frequencies below 150 Hz are challenging to perceive accurately. Thus, an optimal separation of 40 to 60 cm is established to capture a balanced stereo image.

Omnidirectional microphones are commonly used for this type of sound collection. However, caution must be exercised as omnidirectional microphones capture sound equally from all directions, including the audience area. Therefore, careful consideration of microphone placement is necessary to achieve the desired sound balance.

The placement of these microphones is similar to that of the XY pair, positioned approximately 3.5 metres from the musician. However, in this case, the microphones are placed at a higher height, around 2 metres, and angled slightly downwards. As a general guideline, a distance of about 0.5 metres is recommended between the microphones when recording chamber groups. This spacing helps to capture the nuances of each instrument while maintaining a cohesive stereo image.

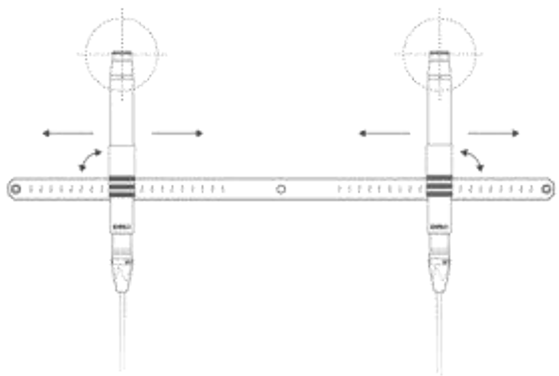

Figure 40 - AB technique (DPA Microphones, 2016).

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2.3.3 Implications for Microphone Placement and for some Musical Instruments and Practical Situations

Each musical instrument possesses unique characteristics in sound emission, necessitating careful consideration of microphone placement to capture its essence accurately. Below, we outline some peculiarities and fundamental principles for effective microphone placement.

The Guitar

The sound of a guitar is primarily amplified by its soundboard, which resonates through the sound hole, akin to a loudspeaker. When positioning microphones for guitar recording, it's crucial to understand these acoustic dynamics. Placing a microphone near the guitar's body can yield satisfactory results if done correctly. Typically, positioning the mic closer to the neck can emphasise high frequencies, while placing it nearer to the bridge or back can have the opposite effect.

Considering the radiation modes of a guitar, it's evident that a microphone aimed at the guitar's body can capture its sound effectively when placed correctly. For instance, a cardioid microphone positioned approximately 80 to 100 centimetres away from the lower part of the guitar's neck will maintain consistent intensity across frequencies.

Understanding these nuances in microphone placement allows for optimal sound capture, ensuring that the unique tonal qualities of the guitar are faithfully reproduced. By strategically placing microphones, engineers and musicians can achieve desired sonic characteristics and enhance the overall listening experience.

Moreover, when recording other instruments, such as the violin or piano, similar considerations apply. For example, with the violin, microphone placement can significantly impact the timbre and clarity of the sound. Placing the microphone closer to the bridge can result in a brighter sound, while positioning it closer to the fingerboard can yield a warmer tone. Similarly, when recording a piano, placing microphones above the hammers can capture the percussive quality of the instrument, while placing them near the strings can emphasise the resonance and sustain.

Overall, understanding the acoustic properties of each instrument and experimenting with microphone placement is essential for achieving optimal sound quality in recordings. By carefully considering these factors, engineers and musicians can enhance the richness and depth of their recordings, creating a more immersive and engaging listening experience.

The String Quartet

The mechanics of bowed string instruments are akin to those of guitars, albeit with differences in how the strings' vibrations are initiated – one by plucking and the other by bowing. However, their sonority and, consequently, the method of capturing their sound, are distinct. Like guitars, the soundboard of string instruments amplifies the vibrations of the strings and projects them forward.

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The sound produced by string instruments exhibits stable characteristics over time. When using a bow, the sound waveform typically features a short period of increasing amplitude followed by a constant phase while the bow is in motion. Consequently, the sound captured by a microphone aimed directly at the instrument's body shows minimal variations in response to changes in position or distance. This stability in sound behaviour simplifies microphone placement considerations, allowing for consistent results regardless of slight adjustments in positioning.

The Flute

The flute exhibits unique characteristics in sound production due to its design, where sound radiates throughout its body based on the placement of uncovered holes. Its acoustic behaviour resembles that of a tube with both ends open, with one end at the mouthpiece and the other at the first uncovered hole. However, the flute's complex fingering system results in the creation of nodes in the pressure wave at intervals between covered and uncovered holes.

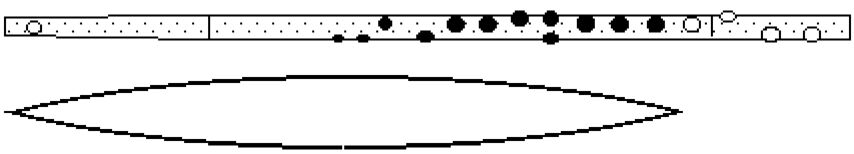

Figure 41 - Pressure wave formed inside the flute for a simple position (Wolfe, 2006).

As a result, when playing the flute, sound emanates from multiple points along its length. Thus, achieving a balanced sound requires precise microphone placement to capture the desired tonal qualities accurately. Depending on the specific fingering used, the flute's sound may vary in brightness and intensity. Generally, positioning the microphone closer to the embouchure produces a brighter sound with a higher air load, while placing it nearer to the bottom results in a darker, softer tone.

Understanding these nuances in flute acoustics is crucial for recording engineers and musicians seeking to capture its full range of timbres effectively. By experimenting with microphone placement and considering the flute's unique sound production mechanisms, optimal results can be achieved in recordings, ensuring faithful reproduction of its rich and versatile sonic characteristics.

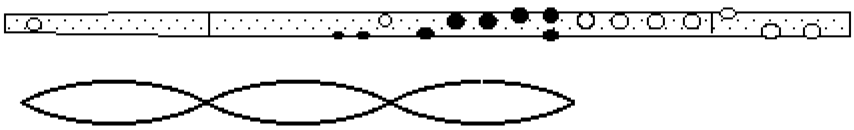

Figure 42 - Pressure wave formed inside the flute for crossed positions (Wolfe, 2006).

The Piano

Recording a piano requires careful consideration of its unique acoustic properties to capture its full range of tones accurately. Here are some essential guidelines for optimal piano recording.

- **Directionality of frequencies –** Different frequencies spread from the piano in various directions. High frequencies, responsible for clear and brilliant tone colours, predominantly spread through the open lid diagonally upwards. Therefore, the microphone should never be positioned below the level of the upper surface of the piano cabinet. Ideally, it should be placed diagonally next to the open lid at a certain distance to capture these frequencies effectively.

- **Microphone placement** – The placement of microphones is crucial and varies depending on the acoustic properties of the recording space. In a dry room or environment, the microphone should be placed further away to avoid capturing unwanted mechanical noise from the piano mechanism and the damping mechanism. Conversely, in a highly acoustic hall or room, the microphone should be positioned closer to the piano to ensure clarity. It is important to avoid placing the microphone 'inside' the piano, as this may result in a harsh, metallic tone, suitable for jazz or pop recordings.

- **Room acoustics –** It is essential to ensure that the rear side of the piano is at least 1 metre away from the wall in the recording room. This prevents bass frequencies from being muffled and ensures clarity throughout the tonal range. In small rooms with limited space, positioning the piano against the wall can result in poor sound quality.

- **Dynamic level adjustment –** It is important to adjust the dynamic level of the recorder carefully. It is recommended to monitor the level as someone plays chords at maximum volume simultaneously in the treble and bass registers. In smaller rooms, dynamic levels are

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typically lower to prevent sound distortion. Manual adjustment is preferable to auto-tuning for greater control over sound quality.

- **Preparation of the piano –** Before recording, it's crucial to remove the lower front panel and to open the top cover of the piano to enhance sound quality. It's recommended to ensure that the piano is fully open during recording sessions to maintain a balanced ratio of low and high tones, ensuring clarity and resonance.

- **Dual microphone setup:** If available, it is advisable to use two microphones for recording. One microphone should be placed close to the piano to capture detailed nuances, and the other one should be positioned as far away in the room as possible. This setup creates an illusion of sound in a larger room due to minimal lag between microphones. Dynamic levels must be adjusted accordingly, considering the acoustic properties of the recording space.

By following these guidelines and adapting to the specific acoustic environment, engineers and musicians can achieve optimal results in piano recordings, capturing the instrument's rich tonal palette with clarity and precision.

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Part 3 – Digital Technologies for Sharing Teaching Materials and Resources.

This part of the handbook focuses on proposing practical solutions based on digital technologies for facilitating interaction with software for musicians engaged in study or overdubbing. These tools allow customization of essential musical parameters in real-time, aligning them with individual study needs and interpretive preferences. While network speeds have improved, the ability to play remotely in synchrony is still in the experimental stage. However, advancements in computing power, particularly in common PCs, coupled with a plethora of software options, including open-source alternatives, have revolutionised music study and production in multi-track audio.

Sophisticated processing algorithms now enable real-time modification of parameters like tempo and pitch, allowing for interactive customization of pre-recorded audio tracks. The systematic use of user-friendly and cost-effective digital tools for sharing musical and extra musical materials represents an innovation for musicians, teachers, and ensemble music students. The goal of these tools is empowering users to tailor their musical experience in real-time, enhancing both study sessions and performances.

This part of the handbook aims to enrich the learning experience for students, offering them practical examples, references, and teaching aids to support their musical development. Through

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the integration of technology and pedagogy, this initiative seeks to empower musicians at all levels to explore, learn, and excel in ensemble music studies.

Studying with computer programs isn't a recent phenomenon; it's been explored for years. Software developers have continuously sought to aid musicians in both offline and online rehearsals. A plethora of software options, both paid and free, are available to support performers not only in instrument practice but also in areas like solfege study. Interacting with software generally occurs in two main ways: either performing alongside pre-recorded sources or engaging in collaborative performances with other musicians located in different places. These technological tools have become indispensable for modern musicians, enriching their practice sessions and expanding their collaborative possibilities.

3.1 Performing with Pre-recorded Audio Tutorials (Partial PlayBack)

Interpretation alongside Partial PlayBack implies two possibilities.

- **Unidirectional** (in which the software plays the pre-recorded source, without interacting in any way with the user);

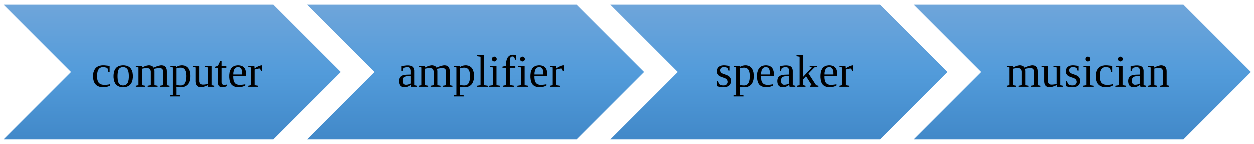

Figure 43 - The unidirectional Partial PlayBack workflow.

- **Bidirectional** (where the software can interact with the interpreter).

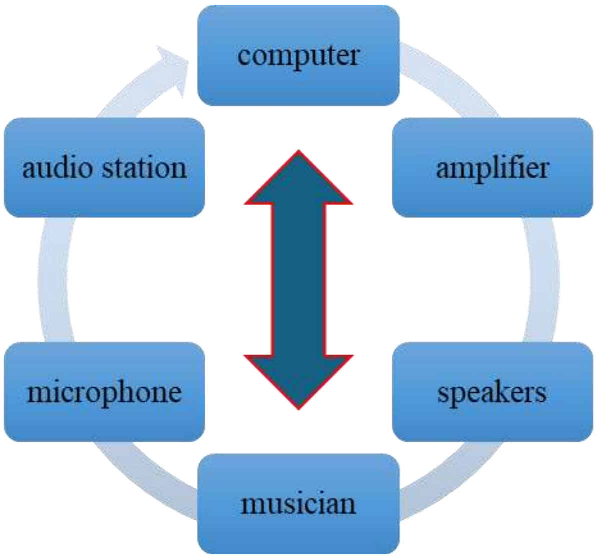

Figure 44 - The bidirectional workflow for interactive Partial PlayBack.

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3.1.1 Hardware Requirements

In both versions, a variety of hardware equipment is necessary to connect with artificial intelligence. For the unidirectional version, which doesn't involve direct interaction with the software, only basic equipment is required: computer, amplifier, and speakers. This setup allows the performer to sing along with pre-recorded sources, typically provided by teachers for study purposes. However, for the second option, where the computer can interact with the performer, additional hardware is necessary. Alongside the computer, amplifier, and speakers, a microphone (preferably a condenser microphone for faithful sound capture) and an audio interface to connect to the computer are essential components.

Unidirectional Interaction

Unidirectional interaction denotes activity transmitted in only one direction, usually from the computer to the interpreter. In this scenario, the interpreter accesses pre-recorded sources, often comprising activities recorded by teachers, for study purposes. Dedicated software enables performers to modify these pre-recorded sources, adjusting tempo or pitch as needed. Various software tools like Audacity, Cool Edit Pro, Sound Forge, or Adobe Audition facilitate these changes. However, it's crucial to make alterations within certain limits to maintain sound quality. Excessive pitch changes (beyond 5-6 semitones) or tempo alterations (beyond 10% of the original time) can result in noticeable distortions.

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One of the primary advantages of unidirectional interaction is its simplicity, making it ideal for studying chamber music without requiring interaction with other performers. Performers have the freedom to repeat sections as necessary to thoroughly learn the score. Additionally, the equipment costs for this setup are relatively low compared to more interactive alternatives.

Despite its simplicity, unidirectional interaction has limitations. It doesn't facilitate the interpretive act as fully as interactive setups, as nuances like agogica and interaction with other performers are absent. Furthermore, while equipment costs are lower compared to interactive setups, they can still be relatively high, particularly for quality microphones and audio interfaces.

Bidirectional Interaction

Bidirectional interaction refers to the activity that propagates in two opposite directions, involving feedback from both ends. In this setup, the performer, along with the computer, receives feedback or can utilise pre-recorded sources that dynamically adjust in real time, such as tempo or pitch changes. It's crucial to understand that the feedback provided by the computer primarily focuses on pitch accuracy and rhythm adherence, rather than assessing the overall performance quality. An example of such a program aimed at aiding pupils/students in music reading development is the Solfy program. This online platform, accessible at www.4solfy.com, assists in solfeggio development. Developed in collaboration with Romania, USA, and Israel, its primary objective is to elevate music education standards in schools. The software offers comprehensive music insights, aids in understanding core musical elements, and fosters correct pitch and rhythm reading. Through interactive features, the program evaluates user performance, records progress, and offers tailored recommendations for further improvement.

3.2 Bidirectional Interaction in Real Time (NMP applications)

The technical side of NMP has been developed in Part 1 of this handbook. This section provides the framework for integrating practical synchronous teaching and performing sessions in the context of pedagogical material sharing. Simultaneous interpretation with instrumentalists situated in disparate locations presents one of the most challenging aspects of current technology. Two primary issues need addressing in this scenario: audio delay and sound quality.

Audio delay stems from variations in internet speed across different locations and the processing speed of sound (encoding, transmission, decoding) by sound cards. Overcoming these hurdles ensures near-instantaneous sound transmission, enabling performances of chamber music works with musicians in remote locations.

Achieving high-quality sound reproduction in remote collaborations necessitates a set of premium-grade devices, commensurate with the corresponding cost. These devices must effectively capture, process, and reproduce sound to meet the standards expected in professional music interpretation.

In both unidirectional and bidirectional versions, a series of hardware equipment is needed to connect with artificial intelligence. For the unidirectional version, which does not involve direct

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interaction with the software, only a computer, an amplifier, and a series of speakers are needed, allowing the performer to sing along with the pre-recorded source. However, for the bidirectional option, besides the computer, amplifier, and speakers, additional equipment such as a microphone (preferably a condenser microphone for faithful sound capture), and an audio interface are necessary. Unidirectional interaction is relatively simpler for studying chamber music, while bidirectional interaction allows for more dynamic engagement but requires higher equipment costs.

Conclusions

The new In Media Stat Virtus Method has led to significant advancements in distance training for ensemble music, particularly in integrating digital technologies and innovative tools to overcome geographical barriers and enhance the educational experience. The project demonstrated how Networked Music Performance, Partial PlayBack and sharing techniques for musical and extra musical materials can enable blended learning collaborations in music higher education, offering a learning approach that combines the best of traditional methods with new digital possibilities.

The developed guidelines provided a strong methodological and technological framework to address the challenges of distance music education, allowing educators to adapt to changing landscapes and implement hybrid teaching practices. The use of tools like Jamulus, digital score management platforms, and instrument sampling software has maintained high teaching standards, effectively bridging the gap between traditional and remote music education.

Ultimately, the IMSV project has opened new perspectives for music learning, offering a flexible and adaptable model that not only addresses current needs but also lays the foundation for future innovations. This initiative has established a path toward more inclusive and accessible music education, leveraging technology without compromising artistic and educational quality.

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