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5. MODERN TECHNOLOGIES FOR REMOTE PERFORMING IN MUSICAL ENSEMBLES

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Abstract: *During the pandemic, the issue of remote education was seriously raised for the first time, through the use of Internet. Music education has specific activities, such as performing in ensembles, where the usual internet solutions have proven inadequate, especially due to the very high latency. The article presents the results of the research project entitled "Development of solutions for remote musical education", carried out in the "George Enescu" National University of Arts in Iași, whose first objective was to find technical solutions suitable for remote performing in ensembles, solutions which also offers new opportunities for collaboration between institutions located at a great distance, ensuring access to music education for those with disabilities, for those located at a great distance from university centers, as well as streamlining musical productions involving artists located at a distance.*
Key words: *remote music education, performing in ensembles, modern technologies*

1. Introduction

With the spread of Internet communications, their first applications in education and even music education also appeared. However, only the period of the corona-virus pandemic forced, through the isolation imposed on the entire population during 2020-2021, to resort exclusively to remote education. Everything seemed perfectly possible, with immediately available solutions for two-way audio/video communication (Messenger, Skype, etc.), and various software for conferences for participants located in different places. Moreover, the majority of the population had tablets and smart phones that offered the ability to capture sound/images in real time and transmit them over the Internet. However, while these solutions worked more than reasonably in the previous period, once they were used en masse, annoying problems began to appear: poor audio/video quality, frequent, annoying interruptions, lags, etc., all showing that the communications through internet were not as good as it seemed.

Digital communications allow a virtually unlimited number of users, but at some cost, namely a corresponding reduction in the data stream available to each user, which is done by lowering the quality of the image/audio transmission. A lesser-known feature of digital communications is the delay in information delivery. More specifically, after the communication quality has dropped to an acceptable level of intelligibility, the only way to occasionally allow new users to connect is that their information "packets" to wait for a while other people's "packets" are delivered. This delay leads to latency, which is most often imperceptible in ordinary verbal communication. But very quickly the music community found the bitter truth, they could not use Internet communications to play together remotely. It was one of the main reasons why concert activities were stopped during the pandemic, with all the disastrous consequences for musical life and musical education.

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2. The first edition of the research project entitled "Developing of appropriate solutions for remote music education"

The period of the pandemic has passed, fortunately, and the activities of the musical ensembles have restarted. Technical solutions to play remotely in ensembles seem to be no longer necessary, however they can be particularly useful, having the following applications:

- remote music education
- ensuring access to music education for those in isolated areas, far from music education institutions
- ensuring access to music education for people with mobility or other difficulties, such as those with disabilities
- facilitating remote collaboration between musicians/institutions, by drastically reducing the time and costs caused by transport/accommodation, necessary for the preparatory stages.

The idea of finding solutions for these applications, and for remote music collaborations in general, is not new, with several approaches existing over time. Probably the one that has known the widest spread is the "LoLa" project, the name is an acronym derived from "low latency" - developed in Italy by the Conservatorio di Musica "Giuseppe Tartini" from Trieste in collaboration with GARR, the Italian Research and Academic Network, which aims to find low-latency communication solutions that enable playing remotely in ensembles, with members located at a long distance. The first public demonstration took place in 2010, later the system was implemented in many music education institutions in Europe and beyond. The problem of this system is the very high cost of the equipment per user[26], acceptable for a university, but not and for a high school, the latency achieved is still relatively high for high-tempo tracks (more on this to come).

Another way to collaborate remotely has been widely practiced in the pandemic, by making video-clips. More specifically, each "member" of the ensemble recorded himself, audio and video, playing his part, then someone collected all the recordings (transferred via the Internet), did the audio mixing and the video editing. Although it has been a beneficial way for ensemble members to somehow continue the activity in isolation, this approach is not a genuine ensemble performance activity, lacking the most important feature of ensemble performance - interactivity. Also, it is only possible to approach the pieces with a constant tempo, without variations and fermatas, because each performer must record himself singing/playing very rigorously rhythmically, with a metronome, based on which all the recordings are subsequently synchronized.

The project described in this article started in 2022, being carried out within the Multidisciplinary Research Institute in the Arts (hereinafter referred to as ICMA) of the "George Enescu" National University of Arts in Iași (hereinafter referred to as UNAGE), with the main objective of finding solutions with the lowest possible costs that allow authentic ensemble activity, with members located at long distances, through low-latency audio communications over the Internet.

As reference values for latency, the project used the experience of MIDI

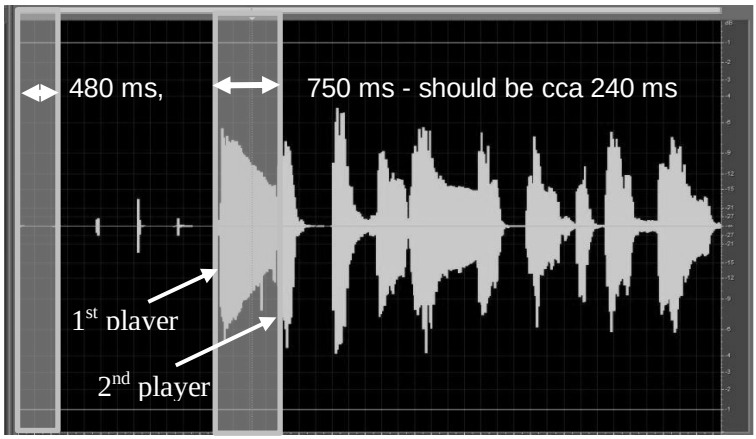
[26] 12,550 Euro-the total cost of the components recommended on the project site https://lola.conts.it/downloads/LOLA_HARDWARE_LIST.pdf (2023)

production, where it was found that when using virtual instruments (VSTi) and a professional audio interface, the value of 12 ms is an acceptable maximum in order not to be able to play those instruments, and also the latency achieved by the LoLa project, with values varying between 40ms - 90ms (depending on the distance between users). To reduce costs, the following strategy was approached:
- using of computers already existing in partner institutions
- the audio connection was prioritized over video, to ensure low latency
- acceptance of high latency for the video connection, visual contact being considered of secondary importance because the synchronization of the performers is mostly done by listening each other.
- using cheap video cameras, of the web-cam type
- using low-cost audio equipment
- using the sound systems already existing in the partner institutions.

The first edition of the project took place between June and October 2022, the activities that were carried out are presented chronologically below.

3. Evaluation of widespread Internet communication solutions

Although it was already obvious that the existing widespread Internet communication solutions (Messenger, Skype, etc.), including those for conferences (Zoom, Microsoft Teams, etc.) are not suitable for remote performing in ensembles, still the latency had to be accurately measured in these cases, this value was to be a reference for the following researches. For this purpose, it was taken into consideration remotely performing in a duet formed by two guitarists, using the Zoom software, with a metronome as a time reference. In the figure below, the metronome clicks can be seen on the left, with a time interval of 480 ms between them, corresponding to a quarter note. Between the attack of the first performer and the second, in the score there is a distance of an eighth note, however the time gap is of 750 ms and not 240 ms, which it should be. It turns out that the latency is about 510 ms. The value is very high, greater than the duration of a quarter note, which makes duet performance impossible. Fig.1



In this case, the very high latency is not only caused by the Internet connection, but also by the fact that the Zoom software, like all Windows operating system applications that use sound, use the operating system's generic audio drivers, which do not take advantage of the capabilities of professional sound interfaces, these generic drivers having a very high latency, of the order of hundreds of

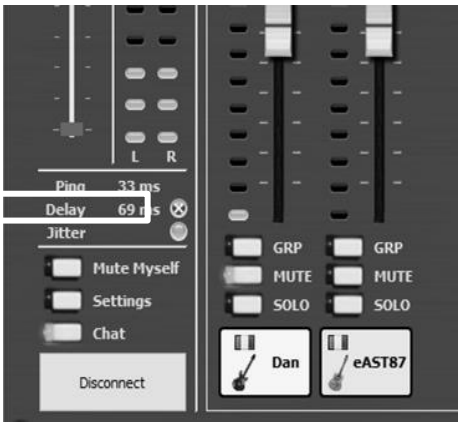
milliseconds. Professional applications avoid this problem by using other types of drivers, provided by manufacturers of professional audio interfaces, such as ASIO[27] drivers, which can provide extremely low latency, as low as 2 ms. The next steps in the research involved investigating specialized software that also used low-latency audio drivers.

4. Evaluation of specialized Internet communication solutions

Toward the end of the pandemic, software specialized in low latency began audio communication over the Internet began to appear, with the aim of facilitating performing remotely. These software reduce latency in two ways. The first is by using a communication protocol that favors the speed of data transmission at the expense of the size of the data flow and, at the same time, search for the shortest access paths through the network to the destination. Of course, they resort to lossy data compression algorithms for the audio information, but these have become very efficient over time, the audio quality should not be noticeably affected. The second way to reduce latency is by using ASIO drivers, though it is necessary to use an external professional audio interface, and not the one integrated in laptops/desktops. Automatically tablets, and even more, smart phones, cannot be used, manufacturers of professional audio interfaces do not produce drivers for their operating systems. One of the software specialized in low-latency audio communication, made precisely for the purpose of being able to play with other musicians remotely, is Jamulus. This program was preferred because it is free and has extended performance optimization possibilities, while constantly displaying the achieved latency.

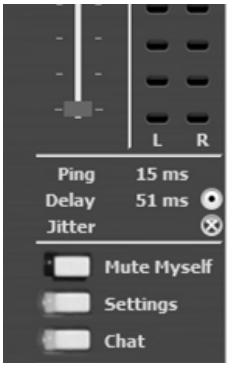
Jamulus provides two ways to connect with another musician, the easiest is by using the server that the other musician creates for this purpose, on his own computer, which is considered a public server. When connecting, the program displays a list of such servers, including the country of origin. The latency obtained by connecting two musicians, members of the research team, through an existing public server from a country as close as possible to Romania was first investigated, at the time of the test a server from the Czech Republic was available.

With this approach a latency of 69 ms was achieved, indicated by the program on the left side with the mention "Delay". This latency is comparable to the performance achieved by the LoLa project, but it is still a high value, which makes synchronization of performers difficult. In addition, the use of an already existing public server means that the performance can be interrupted at any time by other musicians that may want to join the session. Fig. 2



[27] Audio Streaming Input/Output

The next step consisted in creating a private server on a UNAGE computer, connected directly to the institutional Internet network, via optical fiber. With this approach it was possible to achieve a slightly lower latency of 51 ms, as can be seen in the adjacent figure, the only significant advantage being the possibility of playing uninterrupted by the possible occurrence of unexpected users. Fig. 3



For both this stages of the research, the minimum latency provided by the audio interface drivers was used, in order to find out how well the Jamulus software behaves with these values, so that it can ensure a connection without interruptions or other noises specific to driver overload. Both a high-performance audio interface, the RME Fireface 800 (a brand recommended in the LoLa project), and a simple, low-cost audio interface, the M-Audio Fast Track Pro, moreover, an discontinued model, were used. In both cases the interfaces ensured a stable connection, without any noise. This created the opportunity for reducing equipment costs by using a very cheap audio interface. The advantage of a high-quality AD-DA converters is marginal in this approach, given the audio quality is affected anyway by lossy data compression algorithms. Also the multi-channel functionality is not useful, the Jamulus software, and others like it, providing only a two-way stereophonic transmission.

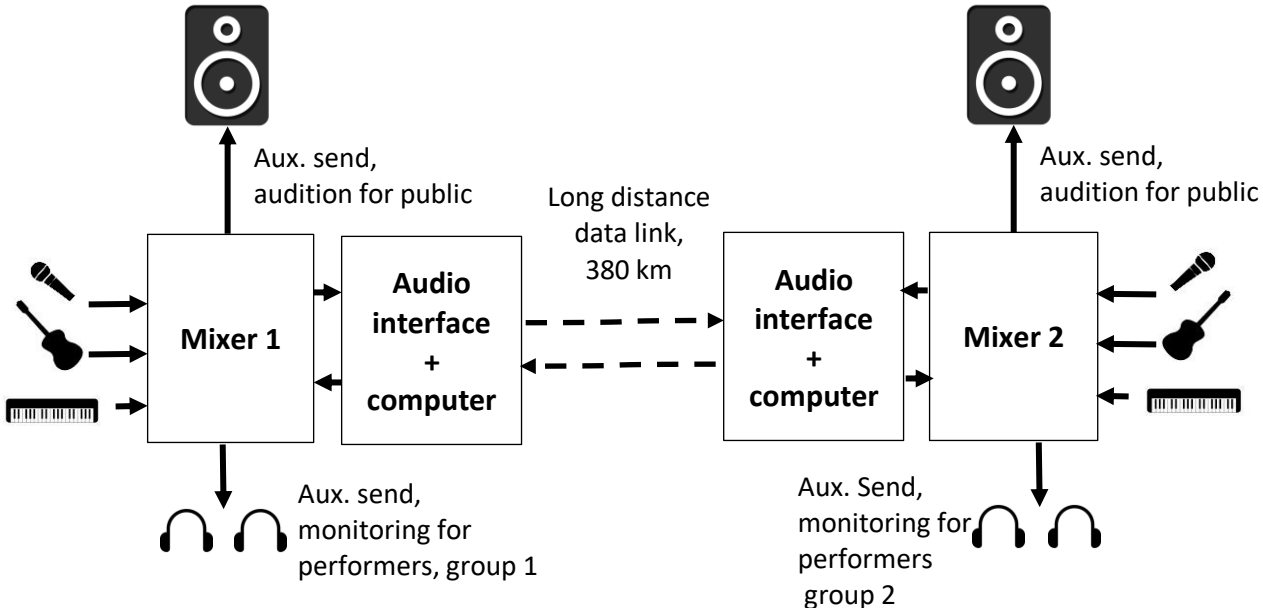
These two tests showed that the latency was drastically reduced, about 10 times, by using the professional drivers, the remaining latency being caused by the Internet connection itself, taking into account the optimization made by the Jamulus program, which prioritizes the transmission speed in relation to the size data flow.

In the first edition of the project, the possibility of reducing the latency even more by using another type of data connection, by resorting to a dedicated data connection, was tested. In order to test all the technical solutions on a real scale, it was decided to collaborate with an institution located at a great distance, over 300 km, the “Tudor Jarda” High School of Music from Bistrița, with the objective of performing a synchronous concert, with two groups of musicians playing together remotely in real time. Also the collaboration was ensuring all the necessary rehearsals prior the concert. For this purpose, a dedicated data line was contracted and installed between the two institutions, provided by the National Society of Radio Communications - RADIOCOM. The connection is similar to one on the Internet, but it is made through a national relay network, being one intended only for the use of two institutions, it does not involve branching or sharing the data flow with other users, so potentially even lower latency could be achieved. The first tests showed a latency of 18 ms, one way, so 36 ms for a two-way connection, which meant almost halving the value obtained with a high-performance Internet connection.

To allow the two groups of musicians to play together using only a two-way stereophonic connection, two audio mixers were used in the two institutions, to which the musicians of each group connected respectively. A challenge was to ensure mutual monitoring, with the possibility of setting the level of each musician and at the same time the possibility for the audience in the halls of the two

institutions to hear what the musicians of the other institution play, without creating audio loops through microphone spill. The solution was to use 3 separate mixes for each institution, one for the monitoring, provided to the performers in the respective hall, one for the audience and one for the monitoring provided to the performers from the other institution. To avoid loops caused by microphone spill, headphones were used by all performers, and the speakers for the audience were placed in front of the performers microphones.

In this configuration, bilateral rehearsals were held with the 2 groups of performers from the two institutions, undergraduates and teachers from UNAGE Iași and students from the Music High School in Bistrița, between September and October 2022, The final activity was a synchronous concert held on October 14 in both places simultaneously, which was a first in Romania at that time. The figure below shows the configuration of the system used. Fig. 4



The photos below show the two halls where the concert took place, the hall in Iași (left) and the one in Bistrița. Fig. 5, 6

The repertoire for the concert included two large families of musical genres, miniature classical works for various solo instruments (performers from Bistrița) comped by piano or guitar (the pianist and guitarist located in Iași) and jazz/pop pieces, to which the soloist and the pianist was located in Bistrița, while the trombone, drums and bass guitar, in Iași. To ensure eye contact for both the performers and the audience, the Zoom conference software was used, accepting that the image was delayed relative to the sound.

The two types of repertoires posed different synchronization problems. The classical one was difficult due to very frequent tempo variations and the existence of many fermata, the jazz/pop one due to the need for very rigorous synchronization at a sustained tempo. During the concert, which actually lasted over an hour, the connection showed slight signs of instability, manifested by slight distortions and very few small interruptions (max 1-2 sec). The interruptions did not caused any delays, with the connection resuming from what was playing at the time.

5. The second edition of the research project "Developing of appropriate solutions for remote music education"

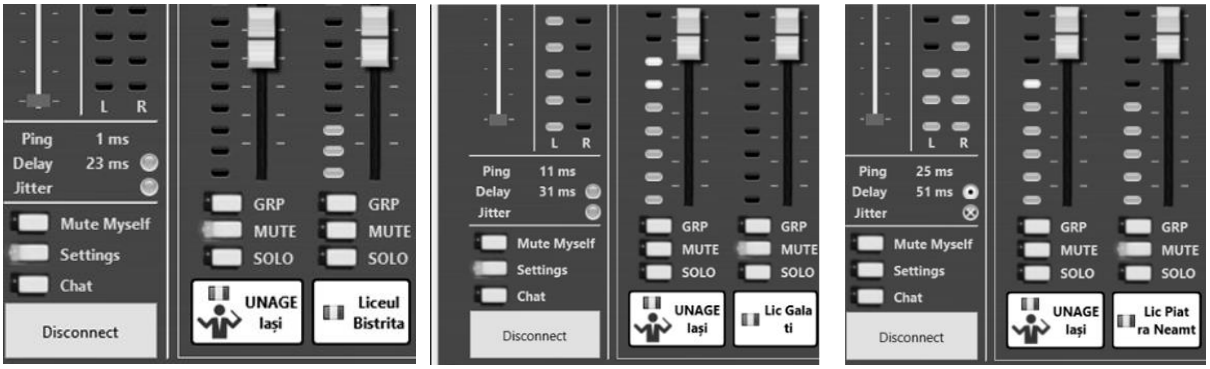
Although the first edition was a success, the configuration and the equipment used raised a series of problems that didn't allow the continuation of the collaboration between the two partner institutions:

- The dedicated data connection was very expensive, involving a very high initial cost for installation, and then a monthly fee. Because of this, the connection was only available for one month, limiting the project's activities. Also an important part of the available budget was used to contract this service, leading to the need to purchase audio equipment as cheap as possible.
- The combination of the dedicated data connection and the Jamulus software resulted in very low latency, but proved to be unstable in operation.
- The high cost of the dedicated data connection limited the project to only two partner institutions.
- The absence of a sound engineer in the partner high school, to operate the audio mixer during the rehearsals and especially in the concert, raised quite big problems. Although an initial mixer setup was made, it proved insufficient, requiring multiple adjustments at each rehearsal and in the concert. The mixer of choice was an analogic one, for easier operation in case of need. Particularly this easy access to the settings led to its accidental disturbing the initial settings, restoring the mix parameters proved very difficult through telephone communication.

The second edition of the project also took place within ICMA-UNAGE, during the periods of June-November 2023, and aimed at solving the problems mentioned above. The new approaches were as follows:

- Using an Internet connection instead of a dedicated data connection, to drastically reduce costs and ensure the connection for an extended period of time. Institutional fiber optic connections were used and terminal computers connected to the network via cable.
− Optimizing Jamulus for minimal latency with stable operation, aiming for a trade-off between latency and audio quality.
- In order to counteract the impossibility of providing sound engineers in the partner institutions, the project resorted to the use of digital mixers that were remote-controlled from Iași (most likely a first in itself)
- Eliminating the cost of the dedicated connection led to the possibility of extending the project to three partner institutions: "Tudor Jarda" Music High School in Bistrița, "Dimitrie Cuclin" Arts High School in Galați and "Victor Brauner" Arts High School in Piatra Neamț, the distances between UNAGE Iași and the respective institutions were between 130-310 km.

The latencies obtained were in general slightly higher comparable to the ones of first edition, still quite low, varying between 23 and 51 ms, which allowed the necessary rehearsals with the partner institutions and performing remotely in 3 concerts synchronously, on the dates of November 22nd (Iași-Bistrița), November 24th (Iași-Galați) and November 27th (Iași-Piatra Neamț). In the photos below the latencies obtained in the case of each institution are shown: Fig. 7, 8, 9



The Internet connection, even broadband, proved as expected, a fluctuating resource, depending on what hour the connection was made, providing a performance varying from excellent to only reasonable. During the rehearsals there were situations when it was possible to resort to the maximum audio quality offered by the program, namely that provided by a data flow of 365 kb/sec in one direction, which is the equivalent of the maximum quality offered by the MPEG-1 Audio Layer format III (popularly known as mp3), at the lowest compression, respectively at a data stream of 320 kb/sec, offering excellent audio quality and low latency. However, during the concerts, it proved necessary to decrease the data flow to 130 kb/sec in one direction, in order to ensure stability and the absence of distortions caused by data fragmentation, which proved still adequate, 128 kb/sec being a minimum for lossy audio compression to ensure reasonable audio quality in stereo.

6. Conclusions

The synchronous concerts took place without the audio interruptions encountered in the first edition, with less distortion and reasonable audio quality. The use of remote controlled digital mixers was a huge plus compared to the previous edition, being more convenient to adjust the monitoring for all participants as well as the mixing for the audience.

Costs have been drastically reduced compared to the previous edition, and involving more institutions in the project could be done. Although this edition has ended, the equipment remains available in the partner institutions, which makes future collaboration possible, such as the producing concerts in partnership, in which the rehearsals take place remotely. Also, future editions can bring new partners in the project, and thus form a network of music institutions that collaborate much more easily using remote performing in ensembles. In the adjacent figure the sound engineer from Iași is operating the local digital mixer with the help of a tablet, in front of him the screen for remote operation of the digital mixer from the partner high school. In the bottom image one of the concerts of the second edition of the project, view from the concert hall of UNAGE Iași. Fig. 10, 11.

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4. https://bel-esprit.ro/beethoven/