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On The Use of Video-Streaming Technologies for Remote Monitoring Of Instrumentation

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Abstract *- The paper focuses on the real-time visualization of the instrumentation involved in distance learning of electric and electronic measurements, in order to allow the students to better understand the real behaviour of the instruments. The work presents an integrated architecture enabling the dispatching of videos during the experimental sessions of the Remote Laboratory Distributed on Geographical Network LA.DI.RE. "G. Savastano". The new proposed architecture is able to adapt the video stream characteristics to the available bandwidth on the client side. In order to evaluate the effectiveness and the versatility of the proposed solution different technologies for video streaming have been analyzed and experimentally tested in the laboratory. In particular, the bandwidth occupation and visualization quality have been analyzed using different streaming technologies and changing the frame rate and the light source in a multi-client scenario.*

Keywords *- web-based training, virtual laboratory, video streaming.*

I. INTRODUCTION

E-learning is considered a high impact service for employer training as well as for supporting regular teaching in high schools and Universities. Currently, the distance learning methodologies included in the term e-learning rely on the Internet potentialities to supply synchronous and asynchronous didactics to the users, that can access to the contents every time and everywhere there is an Internet connection. The Lisbon declaration of European Union in 2000, oriented to improve the education system to give all citizens the same opportunities of improving his/her degree of instruction and to update the competences of the adult people, could be a boost to the diffusion of such learning systems in Europe.

In this framework, the e-learning offers students access to tools and course materials over the Internet. By distributing tools and materials in this fashion, students isolated from the University environment can still work toward University degrees in most offered fields.

In order to produce an e-learning course a cooperative effort is necessary, where different professionals work together with the teacher with the only objective to serve a community of learners [1,2]. The majority of such courses in the technical and scientific fields integrate interactive software tools limited to simulations [3-5]. For this reason an additional laboratory activity should be provided for on-line teaching applied to scientific domains, considering that the web adaptations of software packages such as LabVIEW allow control of experiments over the Internet [6].

The remote control of instrumentation and the execution of real experiments via Internet are topics of interest for many researchers of different scientific fields [7-14]. A lot of solutions have been developed to provide on-line courses including the instrumentation remote control, but these aren't standard solutions and don't allow to trace the operations of the students in order to monitor step by step their knowledge status [15,16]. A possible solution, Remote Laboratory Distributed on Geographical Network LA.DI.RE. "G.Savastano" (http://www.misureremote.unisannio.it), that considers also these basic aspects, has been proposed in [17].

The displaying of instruments during a remote experiment, in addition to the VI front panel, is a relevant aspect of the learning process, because it greatly increases the realism of the laboratory activity giving, in the mean time, a view on the real front panels. The student, in fact, should be put in condition of using the real instrument when he/she will use it outside the remote laboratory. The only way to obtain such results without renouncing to simple and usable graphical user interfaces is to provide the student with both the VI front panel and a real-time video of the instruments.

The paper proposes a flexible system that manages both the real-time visualization of the measurement instrumentation on the remote desktop and data flows concerning the experiments on real measurement instrumentation. The proposed solution ensures the remote monitoring of the instruments employing digital cameras and video streaming technologies for a band-efficient transmission of the real-time videos. Moreover, the system sets the video frame rate and resolution according to the available bandwidth on the client side and the number of clients contemporarily accessing the LA.DI.RE. "G. Savastano".

The paper describes in detail the proposed solution and shows the tests carried out on the new architecture. In particular, the bandwidth occupation and the visualization quality have been estimated versus frame rate, compression algorithms and light source. Moreover, the dynamic

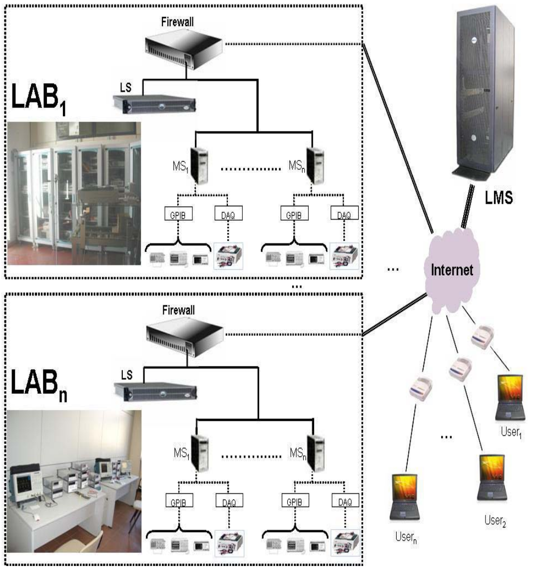

Fig.1. LA.DI.RE. "G. Savastano".

bandwidth assignment has been verified in a multi-client scenario.

In the next sections, after a brief summary of the characteristics of the LA.DI.RE. "G.Savastano" a review of the current technologies for providing videos over Internet is given. Then the architecture of the new system is described. Finally, the results of the test carried out are reported and commented.

II. THE REMOTE DISTRIBUTED LABORATORY

The Remote Laboratory Distributed on Geographical Network LA.DI.RE. "G.Savastano" (Fig.) has been designed and built up in the framework of a project financed by the Italian Ministry of Education, University and Research within the National Operating Programme (PON) 2000-2006. The project has been realized under the patronage of the National Research Association on Electric and Electronic Measurements (GMEE), and with the collaboration of about twenty Italian universities as well as some specialized instrumentation, e-learning and publishing companies such as National Instruments, Tektronix, Agilent Technologies, Yokogawa, Keithley, Rockwell Automation, Didagroup, Augusta publishing.

The LA.DI.RE. "G.Savastano" has the main goal of enabling students to remotely and interactively execute experiments on real measurement instrumentation accessing a set of different geographically distributed laboratories. The initial infrastructure is composed of two laboratories located at the University of Sannio in Benevento, Italy and at the University "Mediterranea" of Reggio Calabria, Italy (Fig.1).

The LA.DI.RE. "G.Savastano" architecture is centered on a Learning Management System (LMS) in order to integrate innovative functionalities to enable students to remotely perform real measurement experiments through common Web browsers, without the necessity of specific hardware and software components installed on client side, as described in [17].

III. CURRENT VIDEO STREAMING SOLUTIONS

The main problem concerning the real-time displaying of the real front panels of the instruments on the remote clients through a Web browser is that the bandwidth occupation is directly proportional to the video quality in terms of frame rate and resolution. The higher is the video quality, the higher is the required bandwidth. The typical bandwidth of an ISDN or even an ADSL connection would be easily saturated trying to transmit a non compressed video in the Internet.

An efficient data transmission can be ensured relying on specific software components, called codecs, whose main tasks are: (i) encoding and compressing the raw video stream coming from an acquisition device; (ii) decoding and expanding the compressed file to rebuild the original video. Some of them, during the encoding phase, provide a packet switched data stream to be sent over Internet and, before the decoding phase, rebuild the data stream coming from Internet. Such components, called video-streaming codecs, are used within several applications from video-conferencing to surveillance and video on demand over Internet as they provide a good trade-off between quality and bandwidth occupation and can support real-time videos.

Due to the economic relevance of codec applications, a lot of efforts are currently made to improve the compression factor while preserving a good video quality, resulting in a continuous evolution of such tools.

Currently, the most widely used video codecs are H.261, H.263, JPEG, MPEG1, MPEG2 and H.264/MPEG4.

H.261 was targeted at teleconferencing applications and is intended for carrying video over ISDN - in particular for face-to-face videophone applications and videoconferencing. The encoding algorithm includes a mechanism which optimises bandwidth usage by trading picture quality against motion, so that a quickly-changing picture will have a lower quality than a relatively static picture. The codec H.263 guarantees the same image quality of codec H.261, but it requires a transmission bit rate that is one half of H.261 one [18]. JPEG has been designed for compressing either full-color or gray-scale images of natural, real-world scenes. It works well on photographs, naturalistic artwork, and similar material; not so well on lettering, simple cartoons, or line drawings. The JPEG codec allows to reduce the images of a compression factor 1/50 and to choose a frame rate different from the original video one. The overall video quality factor including the compression factor and frame rate can be set choosing a quality index in the interval (0...1) [18].

MPEG 1, 2 and 4 are currently accepted and developing standards, for the bandwidth efficient transmission of video and audio, respectively. MPEG-1 requires expensive hardware for real-time encoding while decoding can be done in software. Most implementations consume a large fraction of the processing power of a high-end processor. MPEG-1 does not offer resolution scalability and the video quality is highly susceptible to packet losses. MPEG 2 extends MPEG 1 by including support for higher resolution video and increased audio capabilities. Compared with MPEG-1, it requires even more expensive hardware to encode and decode. It is also prone to poor video quality in the presence of losses for the same reasons as MPEG-1. Both MPEG-1 and MPEG-2 are well suited to the purposes for which they were developed. For example, MPEG-1 works very well for playback from CD-ROM, and MPEG-2 is great for high-quality archiving applications and for TV broadcast applications [19].

H.264/MPEG-4 supports video compression for video-conferencing and video-telephony applications. The H.264 video codec has a very broad range of applications that covers all forms of digital compressed video from low bit-rate Internet streaming applications to HDTV broadcast and Digital Cinema applications with nearly lossless coding. H.264/MPEG-4 has achieved a significant improvement in the rate-distortion efficiency – providing a factor of two in bit-rate savings compared with MPEG-2 video, which is the most common standard used for video storage and transmission. The coding gain of H.264 over H.263 is in the range of 25% to 50%, depending on the type of application [19]. At the moment there is not a general scheme that associates the right codec to a specific application, each codec is used in different fields and for different applications leading to different results. Moreover, concerning real-time videos, the filming conditions influence the quality and bandwidth occupation in a different manner for different codecs. Therefore, in order to choose the right codec for the remote monitoring of the instrumentation to be integrated in the LA.DI.RE. "G.Savastano" system, an experimental approach has been followed, measuring the performances the different codecs in different filming conditions, as described in the next Section.

Only the most diffused codecs have been taken in account because they already have been proved robustness on the field. Moreover, they are already installed on a wide number of Internet-connected PCs, so the students should not download more plug-ins. MPEG-1 and MPEG-2 codecs have been excluded as they don't support real-time video transmission over Internet, while H.261 is less efficient than H.263. Therefore, in the present work, only the H.263, JPEG and MPEG-4 have been considered.

The better solution for delivering the instrument videos contemporarily to the Virtual Instruments (VIs) has been searched through an experimental approach, measuring the average value of bandwidth occupation for all the chosen codecs while changing some reference parameters as the light source, the frame rate, the frame sizes, and the camera distance from the instrument.

IV. VIDEO MONITORING OF THE INSTRUMENTATION

A method to manage the video streaming data coming from different codecs has been proposed in [20]. Within that

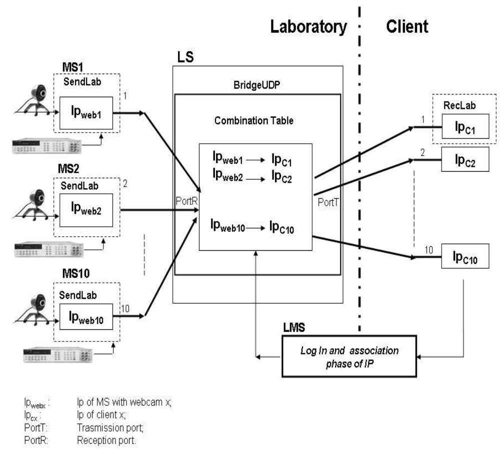

Fig. 2. System components for real-time video of instrumentation

work it has been proposed to acquire a video from each instrument of the measurement laboratory by means of a video acquisition device connected to the Measurement Server (MS). A video bridge component is responsible for sending the instrumentation video received from the MSs to the requiring user. The proposed approach relies on the Real Time Protocol (RTP) instead of the Remote Desktop Protocol (RDP) used for remote access to the VIs. In fact, RDP is not effective nor flexible for the video transmission since it doesn't permit to modify parameters such as codec, video formats, frame rate and involves a very high bandwidth occupation.

Starting from the first analyses on the video bridge reported in [18], in order to deliver the video streaming to the user during the remote control of the experiment in a lab session, a new set of components has been developed to redirect videos and data coming from the MSs to the students.

A specific system has been implemented to control the remote visualization of instrumentation integrated with the Bridge Service already operating in the Laboratory Servers (LSs). The system has been developed in Java to guarantee the compatibility with the existing bridge service. Moreover, it has been possible to adopt a unified framework for integrating different video codecs, the Sun Java Media Framework (JMF). JMF is a framework to process time-based media within Java applets or applications. It supports the RTP and RTCP protocols and permits to handle multiple video codecs and media formats through a ease-to-use plug-in-based architecture. By using JMF, it has been possible to add the remote monitoring of the instrument front panels to the existing user interfaces of the experiments without redesigning the whole LA.DI.RE. "G.Savastano" software architecture. The software components developed for delivering the instrument videos are the following (Fig.2):

- *SendLab (Send Laboratory):* this component is an application running on each MS, where videocameras are installed to film the instruments. The main target of this application is to detect a *capture device,* that in the first experimental phase consisted in a Creative NXPro webcam for each MS, and in the second experimental phase in an Axis 207 IP Camera. The choice of the video acquisition device was discussed in [20].

- *BridgeUDP:* this application is the system core and performs a bridging on RTP flows coming from MSs and sends them to requiring clients. In LA.DI.RE. “G.Savastano” the bridge application runs on the LS. The bridge implements the Ip mapping, replacing the Ip of LS with the client Ip (destination Ip).

RecLab (Receive Laboratory): this application allows the user to receive the RTP flow and to achieve the instrument displaying on the student’s PC through a Java applet. This is the only new component to be downloaded by the student. After the user request for a specific measurement experiment, the LMS verifies the experiment availability and communicates to LS the connection data of the remote client, as described in [17].

Then, the LS starts a direct communication with the client delivering both the instrumentation access through the VI front panel and the video stream transmission coming from the camera associated to the chosen experiment. According to the number of active remote connections and the available bandwidth on the client side, the system assigns the maximum video quality. Before starting the experiment, the student can choose among different displaying options such as no visualization, photo displaying with different resolutions, visualization of one frame per second with different resolutions, visualization of 10 frames per second with different resolutions and visualization of 25 frames for second with different resolutions. Only the options compatible with the available bandwidth estimated by the system will be enabled on screen.

V. PRELIMINARY TESTS

Here, the first results concerning the analysis of bandwidth occupation and visualization quality obtained using different video codecs are reported. The performance evaluations have been conducted in the LA.DI.RE. “G.Savastano” of University of Sannio.

The test phase has been divided in two parts. The first part concerning the selection of the best filming and encoding conditions; the second one concerning the capacity of assigning the bandwidth when multiple clients are connecting.

As above reported, the codecs used for the measurements are H.263, JPEG and MPEG-4.

For the first experimental evaluations, involving H263 and JPEG codecs, the following devices were used:

- LMS: Dell PowerEdge 4210;
- LS: Pentium IV 3.0 GHz, 1GB of RAM;
- MS: Pentium IV 3.0 GHz, 1GB of RAM;
- Webcam: Creative NXPro;
- Displayed measurement instrument: Agilent 3458A Digital Multimeter;
- Client: Athlon AMD 1.7 GHz, 512 MB of RAM.

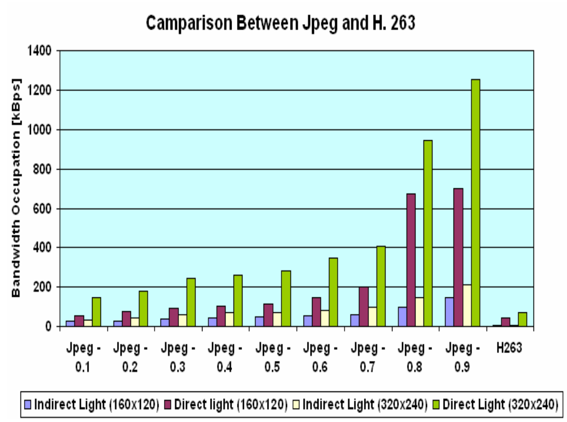

Fig.3. Comparison between codecs H.263 and JPEG.

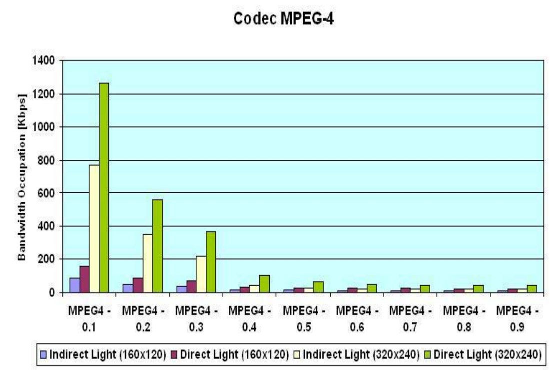

Fig.4. Trend of bandwidth occupation for codec MPEG-4.

The tests have been carried out on a Fast Ethernet LAN. The quality factor has been varied in the range [0...1] for JPEG codec while it is equal to 0.5 for the codec H.263.

Frame sizes have been chosen to be 352x288 and 176x144 for H.263 codec and 320x240 and 160x120 for JPEG codec.

The filming conditions have been simplified as possible fixing the camera distance from the instrument to 50 cm without using zoom lens. Of course, in order to capture front panels with different dimensions, the camera distance should change for different instruments. The sun light has been excluded as possible light source due to its extreme variations during the different hours of the day and different seasons of the year. Therefore, artificial light sources have been considered directly focused on the instrument or pointed to the room walls. The indirect light is a neon lamp, while the direct light is a halogen spotlight (100 W) located at a distance of 50 cm from the displayed instrument.

For each codec, frame size and light source 30 bandwidth measures have been taken using the CommView Packet Analyzer software, ver. 5.0 installed in the LS and calculating their average and standard deviation. A first comparison of the average values is reported in Fig.2 while a full detail of the measures is reported in Tab.1. Fig.2 shows clearly that the H.263 codec is better than codec JPEG. Moreover, for the last one the bandwidth is highly variable, as it can be seen from

Tab. 1. Preliminary experimental results.

	Frame Sizes (320x240)			
JPEG	**Indirect Light**		**Direct Light**	
Quality factor	*Bandwidth[kBps]*	*Std.Dev.*	*Bandwidth[kBps]*	*Std.Dev.*
0,1	33,426	2,384	145,918	0,720
0,2	43,559	0,960	180,361	0,636
0,3	59,700	0,077	243,630	1,580
0,4	68,238	0,112	258,068	0,920
0,5	69,859	0,152	278,803	8,183
0,6	82,410	0,278	347,025	16,852
0,7	97,379	0,280	406,328	18,915
0,8	144,408	0,626	943,425	20,655
0,9	212,769	0,595	1256,033	29,450
	Frame Sizes (160x120)			
JPEG	**Indirect Light**		**Direct Light**	
Quality factor	*Bandwidth[kBps]*	*Std.Dev.*	*Bandwidth[kBps]*	*Std.Dev.*
0,1	25,011	0,123	51,656	0,795
0,2	29,122	0,252	76,041	1,152
0,3	39,154	0,189	90,458	2,149
0,4	42,424	0,239	103,957	4,244
0,5	50,168	0,524	115,213	7,440
0,6	53,027	0,294	145,502	9,421
0,7	61,832	0,093	198,171	16,348
0,8	98,077	0,766	675,753	1,059
0,9	146,358	0,796	702,504	40,515
	Frame Sizes (352x288)			
H.263	**Indirect Light**		**Direct Light**	
Quality factor	*Bandwidth[kBps]*	*Std.Dev.*	*Bandwidth[kBps]*	*Std.Dev.*
costant(0,5)	7,996	0,209	68,126	0,449
	Frame Sizes (176x144)			
H.263	**Indirect Light**		**Direct Light**	
Quality factor	*Bandwidth[kBps]*	*Std.Dev.*	*Bandwidth[kBps]*	*Std.Dev.*
costant(0,5)	5,183	0,073	42,023	0,473

the estimated dispersion in Tab.1. Finally, the JPEG occupied bandwidth is very high for high quality factor values.

Fig.3 also underlines the better performance (lower bandwidth occupation) of both codecs with indirect light respect to direct light. This could be caused by the highly reflective surface of the used instrument. The light grey multimeter front panel, in fact, reflects to the videocamera the spotlight intensity variations.

For these reasons, the first evaluation of the experimental results suggested to use the H.263 codec as it guarantees a lower bandwidth occupation respect to JPEG one in an environment with indirect illumination.

Then, the codec MPEG-4 has been added by changing the video acquisition device with an IP camera including the encoding capability. The tests have been carried out involving the following devices :

- LMS: Dell PowerEdge 4210;
- LS: Pentium IV 3.0 GHz, 1GB of RAM;

Tab.2. Preliminary experimental results for codec MPEG-4.

	Frame Sizes (320x240)			
MPEG-4	**Indirect Light**		**Direct Light**	
Compression factor	*Bandwidth[Kbps]*	*Dev. Std.*	*Bandwidth[Kbps]*	*Dev. Std.*
0,1	771,025	71,903	1263,133	107,912
0,2	351,328	65,684	564,090	104,525
0,3	218,125	56,606	367,433	90,788
0,4	45,946	38,307	105,989	55,587
0,5	28,501	28,776	66,164	44,588
0,6	23,106	21,711	51,401	33,755
0,7	21,062	18,395	45,791	28,589
0,8	23,084	15,691	41,917	24,187
0,9	22,393	13,446	41,746	21,403
	Frame Sizes (160x120)			
MPEG-4	**Indirect Light**		**Direct Light**	
Compression factor	*Bandwidth[Kbps]*	*Dev. Std.*	*Bandwidth[Kbps]*	*Dev. Std.*
0,1	87,193	24,296	158,628	37,871
0,2	46,827	21,567	88,831	31,736
0,3	38,172	18,338	69,982	25,806
0,4	18,961	10,912	35,434	15,876
0,5	15,430	8,691	29,978	12,935
0,6	13,553	6,540	26,067	10,069
0,7	12,890	5,676	25,482	8,615
0,8	12,088	4,952	23,652	7,639
0,9	11,412	4,436	22,610	6,699

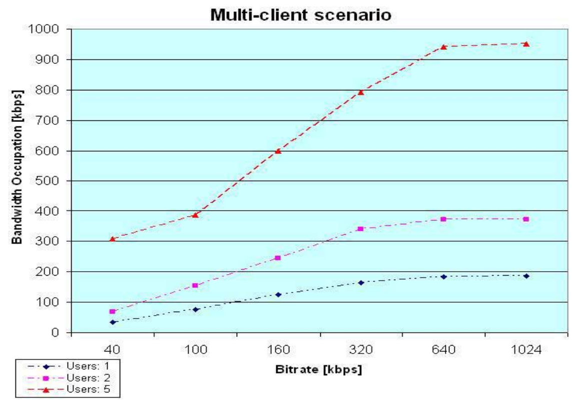

Fig.5. Trend of bandwidth occupation for a multi-client scenario.

- MS: Pentium IV 3.0 GHz, 1GB of RAM;
- IP Camera: Axis 207;
- Displayed measurement instruments: Agilent 33220A Waveform Generator and Tektronix TDS 5032B Oscilloscope;
- Client: Athlon AMD 1.7 GHz, 512 MB of RAM.

The first tests regarding this codec have been carried out on a Fast Ethernet LAN, changing the compression factor in the range [0...1], where 0 represents the maximum possible compression and 1 the minimum possible compression. Moreover, the frame sizes have been chosen to be 320x240 and 160x120, and have been used different light sources, like previous tests on codecs H263 and JPEG. The results reported in Tab.2 and in Fig.3 show a strong bandwidth decrease versus the compression factor increase. In the same measurement conditions, the bandwidth occupation of MPEG-4 codec is very low compared to the other reference codecs, as it can be seen comparing Fig.3 and Fig.4. In fact the measurement unit of graph concerning codecs H263 and JPEG is kilobyte (kB) while the unit of graph concerning codec MPEG-4 is kilobit (kb).

More tests have been performed to analyse the bandwidth occupation changing the user number that, accessing to a specific measurement experiment at the same time, choose also the visualization of real instrumentation front panel. In particular, the following encoding parameters have been fixed:

- Frame sizes: 640x480;
- Color level: 50%;
- Compression factor: 0,50;
- Frame rate: 25 fps.

This parameter configuration has been chosen because represents a critical event. In fact it allows the best quality of visualization but at the same time causes the highest bandwidth occupation.

The user number that access at the same time to reference experiment is: 1, 2 and 5 and the user bitrate changes in range [40, 100, 160, 320, 640, 1024] kbps. For each couple (Bitrate, User number) 50 bandwidth measures have been taken using the CommView Packet Analyzer software installed in the LS and calculating their average and standard deviation.

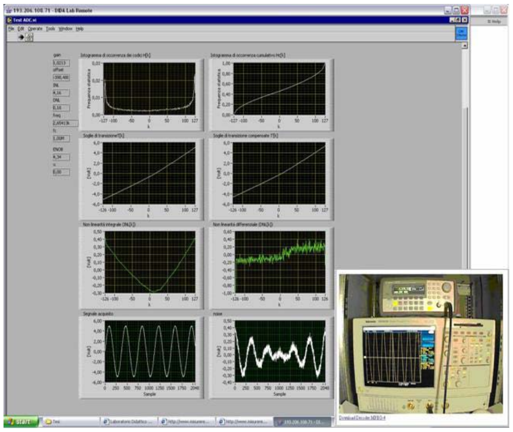

Fig.6. Visualization and Control of measurement instrumentation.

Fig.5 shows the bandwidth occupation trend for each couple of values (Bitrate, User number) and underlines the bandwidth increase in regard to users number increase that access to selected experiment at the same time, showing not linear characteristics.

V. CONCLUSIONS

The paper has presented an innovative platform for e-learning that integrates a classical LMS with remotely accessible measurement laboratories through the Web. The paper has analyzed more in detail the problem of the remote displaying of real instrumentation front panels adopting video streaming technologies. In particular, the authors have carried out a detailed analysis on codecs H.263, JPEG and MPEG-4, showing also a multi-client scenario with several users connected to a specific measurement experiment at the same time. The first evaluation of the experimental results suggest to use the codec MPEG-4, because it assures a lower bandwidth occupation respect to other video codecs considered in this work. Now, with the integration of the developed video architecture in the general system it's possible for students both to control and to observe the measurement instrumentation installed in the LA.DI.RE. "G. Savastano" at the same time, as shown in Fig.6.

Finally, other detailed tests are being carried out when multiple clients are connecting to the system via Internet.

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