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COMMUNICATION STRUCTURE FOR DATA MANAGEMENT AND REMOTE CONTROL OF A MOBILE PLATFORM

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Lucrarea abordează tema managementului de la distanţă al datelor obţinute în urma investigaţiilor optoelectronice efectuate asupra obiectelor de arta şi patrimoniu cultural. Se analizează modul în care infrastructura de investigare poate utiliza internetul ca mediu virtual de transfer a datelor între platforma mobilă, situata în teren, şi utilizatori situaţi la distanţă. Se estimează lărgimea de bandă necesară pentru a asigura controlul de la distanţă şi comunicaţiile video şi audio cu operatorii din teren şi sunt prezentate rezultatele experimentale obtinute. O conexiune stabilită printr-un router 3G conectat la reteaua mobila de internet este o soluţie viabilă şi ieftină. Lucrarea dezvoltă un concept referitor la organizarea internă a echipamentelor într-o reţea locală la care se pot conecta în mod cablat sau wireless, soluţie care oferă o mai buna mobilitate în teren.Se pot deschide teleconferinţe între utilizatori din mediile academic şi ştiintific şi, respectiv, operatorii din teren, prin folosirea tehnologiilor VoIP iar echipamentele de calcul din amplasament pot fi operate de la distanţă, prin utilizarea aplicaţiilor software specializate în transferul la distanţă al controlului. Datele experimentale privind capacităţile de transfer ale routerului 3G demonstrează că teleoperarea în bune condiţii este posibilă dacă se utilizează scheme adecvate de codare/decodare pentru compresarea imaginilor transmise.

.This paper approaches the thematic of remote management of data from optoelectronic investigations performed on objects of art and cultural heritage. It is analyzed how the investigation infrastructure can use the Internet as a virtual data transfer media between mobile platform, located in the field, and remote users. It is estimated the bandwidth needed to provide remote access and video and audio communications with operators in the field and experimental results obtained are presented. A connection established by a 3G router connected to a internet mobile network is a viable and affordable solution. The paper also presents a concept regarding internal organization of equipments within a local area network to which they can be connected either by cable or wirelessly, a solution that offers a better mobility in the field. Remote conferences between users belonging to academic and scientific media and in-situ operators can be opened by using VoIP technology and control of the in-situ computers can be taken from distance using wide spread, free remote control software applications. Experimental data regarding upload and download capabilities of the 3G router prove that reliable operation from distance is possible if appropriate encoding/decoding schemes for images compression are used.

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1. Introduction

Advanced techniques of conservation - including investigation, diagnosis, and restoration - are now more sophisticated and specific rules must respect all norms regarding the research systems - chemical and physical principles, accuracy and repeatability, higher sensitivity level for achieving higher accuracy classes. Optoelectronic methods are the most popular because provide certain and often unique advantages such as transportability or even portability, operating without sampling or sample preparation, response in very short time, sometimes in real time. These methods are also ecological (no chemical materials, dangerous radiation or toxic gases are involved and no wastes which have special handling or storage regimes are generated) and aren't creating ethical issues.

This paper continues an extensive research on complementary methods and techniques of investigation and diagnostic of artifacts whose conservation status is evaluated. Investigation by optoelectronic means (which are non or minimally invasive methods) raises certain aspects which are now better mastered. We recall here the techniques of laser spectroscopy (LIBS, LIFS) [1], thermography, 3D laser scanning [2], laser Doppler vibrometry and Ground Penetrating Radar mapping [3]. Advanced data processing and interpretation are possible by corroborating data and composing functions used in investigation. Data overlaying permits the assessment of the state of conservation with a higher degree of accuracy and allows simulation and prediction studies regarding the behavior of the ensemble and the subsequent designing of the conservation strategy [4].

In parallel with improvement of investigation and monitoring methods, remote utilization and control of the specialized infrastructure by a group of investigators and experts, assisting operators within the *in-situ* autolaboratory, represents a necessary and high-perspective approach.

The quality of the complex product generated by data overlapping is conditioned by the understanding of the correlation between determined quantities, the microscopic, submicroscopic and even nanoscopic geometries of the surface, relations between different resolutions and results of bi- or tridimensional investigations. End-users, restorers and investigators are requesting, along with these working conditions, remote methods of control, data collection and management which have to be functional in the laboratory, but mainly in the field.

Present paper is referring to research facilities provided by ART4ART autolaboratory. Even more, the solution it is applicable, testable and easy to be optimized by direct observation of the results obtained from *in situ* applications.

Therefore, the work deals with a very acute problem directly related to highly specialized advanced techniques with applications in fields such as medicine and conservation. Paradoxically, despite the mentioned techniques are very useful, they are avoided by some restorers as a result of inability to exploit the maximum amount of data by a single expert restorer. Development of methods for data corroboration, based on information management, is the solution sought.

The key to the teleoperation is represented by the communication infrastructure. That's why the paper presents and discusses a comparison between estimated and measured transmission bandwidths that are necessary to be ensured by a mobile Internet connection so that to make possible remote operation of the autolaboratory with reasonable time lags and negligible delays. Due to the high dynamics of the involved data traffic, the necessary bandwidth for downlink and uplink can easily and highly be over or underestimated. The purpose of this paper is to illustrate how these determinations are made in order to ensure realistic expectations regarding teleoperation of *in-situ* equipments. .

2. Considerations on choosing appropriate mobile connection

The mobile platform for *in-situ* investigations can be connected to Internet by using two types of technologies: satellite solution and terrestrial solution. Satellite links are still characterized by prohibitive prices for reasonable communication speeds. Taking into account the scientific domain we refer to, the bandwidth provided by a satellite link is much under the values reached by terrestrial communication systems, for affordable prices.

Communication between remote users and *in-situ* investigation platform takes place over the Internet by using HSPA (High Speed Packet Access) protocol within a mobile telephony network. The 3G router of the mobile *in-situ* platform allows developing of a local area network (LAN) to which the computing devices within the autolaboratory connect to the Internet.

The router is able to reach maximum transfer speeds of 7.2Mb/s for download and 5.7Mb/s for upload when it is connected in HSPA mode. When it is connected to the network in other modes, like 3G, GPRS or GSM, the bandwidth drops significantly to 384kb/s, reaching as low as 57.6kb/s (or lower) for a GSM connection, and it is able to connect to the cellular network in all available operating modes (GPRS-General Packet Radio Service, EDGE-Enhanced Data rates for GSM Evolution, 3G-3rd Generation Mobile Telecommunications and HSPA), depending on their availability.

The 3G router uses the UMTS (Universal Mobile Telecommunications System) mobile cellular technology at 900MHz, which provides some important benefits over 2000MHz frequency band, among which a better propagation over large distances and lower attenuation through the buildings' walls thus ensuring an augmented capacity in urban areas and an improved indoor coverage.

External wideband gain antenna can be connected to the router, and this is a useful technical feature because a gain antenna provides a higher level of the received and transmitted signals, improving the chances to get connected on HSPA system even in areas with a poor signal conditions. Since the router uses frequencies in a wide spectrum, between 900MHz and 2000MHz, the external antenna has to be a wide-bandwidth one. An external antenna having a gain of 13dBi has a significant contribution, producing an effective (or equivalent) isotropic radiated power (EIRP) which is about 20 times larger than the power radiated by the internal isotropic antenna. The power gain is computed by using equation (1):

$$G[dBi] = 10 \lg \frac{EIRP[W]}{IRP[W]} \quad (1),$$

where:

EIRP[W] - equivalent isotropically radiated power, in watts;

IRP[W] - isotropically radiated power (power radiated by an isotropic antenna), in watts;

G[dBi] - power gain of an antenna, reffered to an isotropic antenna.

If losses are neglected, then the effective isotropic radiated power (EIRP) is given by equation (2):

$$\mathrm{EIRP[W]} = 10^{G[dBi]/10} * \mathrm{IRP[W]} = 10^{1.3} * \mathrm{IRP[W]} \cong 20 * \mathrm{IRP[W]} \quad (2),$$

where:

EIRP[W] - equivalent isotropically radiated power, in watts;

IRP[W] - isotropically radiated power (power radiated by an isotropic antenna), in watts.

The signal to noise ratio (SNR) of the received signal will also increase with approximately 13dB, which can make the difference between a poor connection and a stable one.

3. Necessary bandwidths for teleoperation.

The integrated software solution for teleoperation refers to a software package that allows external users to connect to the local network of the mobile laboratory, which is built behind the 3G router. This software package includes applications that facilitates audio-video communication (VoIP), files transferring and controlling of remote computers associated with *in-situ* equipments.

Figure 1 schematically illustrates how the mobile platform (autolaboratory) is used to remotely perform *in-situ* investigations, allowing external users and participants to be directly involved in this process.

Dedicated and widespread free software applications, are used to achieve video-voice connections (VoIP), while files transfer and equipments' control are performed through FTP Server/Client applications and remote control programs. Using such widespread freeware applications, the system accessibility is ensured, so that remote users can connect to the online system very easy.

Communications are structured in two types: human-to-human (H2H) and machine-to-machine (M2M). While the first type refers to keeping a video-audio link with *in-situ* personnel, for inherent interventions on local investigation setups, the second one refers to data exchanges and remote control of the computers associated with the investigation devices.

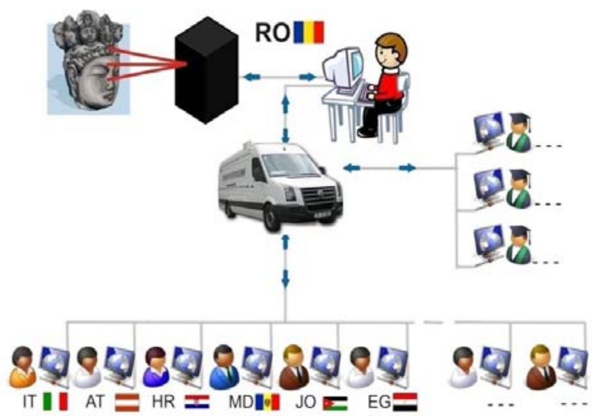

Fig. 1. The mobile investigation platform as a communication and computational node between local operators and remote academic and research media.

At the level of human-to-human (H2H) communication, the autolaboratory uses a VoIP freeware software application which is a hybrid solution between peer-to-peer (P2P) and client-server architectures.

We have chosen this approach because of the good compromise between the quality of the transmitted images and the communication bandwidth required for a video connection.

For one-to-one and group video connections of standard definitions, this software application uses VP8 video codec, while for 720p and 1080p high definitions it uses the H.264 (MPEG-4 Part 10 or AVC - Advanced Video Coding) video codec.

VP8 is an open video compression format which is using *libvpx* software library for both encoding and decoding of the video frames. Because actual VP8 encoding algorithm has been found being much slower and resource-consuming than H.264, a new VP8 encoder, based on x264 framework, is under development at present, so that a standardization of the codecs involved in video transmittals over Internet is to be expected, regardless the chosen video definition.

As it can be found from the literature [5], H.264, known as MPEG-4 Part10/AVC, is the newest MPEG (Moving Pictures Experts Group) encoder.

As H.264 encoder is able to reduce digital video files with more than 80% than Motion JPEG and even with almost 50% than MPEG-4 does, without compromising the image quality, it is to be expected that this encoding scheme will become a standard, at least for the next years.

A comparison between VP8 and H.264 reveals that the two codecs have similar performances regarding the compression ratios over the bit rate, although VP8 is slightly better at slow bit rates. But when it comes to encoding speed, H.264 is 15-20 times faster then VP8 [6].

As a preliminary conclusion regarding H2H communication method, this approach represents a good choice for VoIP (Voice over Internet Protocol) since it uses the most recent audio and video codecs designed to be used within Internet media characterized by low bit rates. As these codecs are providing an increased compression rate compared with their predecessors, without any visible negative impact upon image quality, both the minimum required connection speed and the necessary space for file storage are diminished.

Moreover, the portability of this program makes it suitable even for smartphones, bringing an improved mobility to every potential remote user of the online laboratory.

Table 1 presents some recommendations and estimations of the required bandwidths.

Table 1

Values of download/upload speeds.

Call type	**Minimum download / upload speed**	**Recommended download / upload speed**
Calling	30kbps / 30kbps	100kbps / 100kbps
Video calling / Screen sharing	128kbps / 128kbps	300kbps / 300kbps
Video calling (high-quality)	400kbps / 400kbps	500kbps / 500kbps
Video calling (HD)	1.2Mbps / 1.2Mbps	1.5Mbps / 1.5Mbps
Group video calling (3 people)	512kbps / 128kbps	2Mbps / 512kbps
Group video calling (5 people)	**2Mbps / 128kbps**	**4Mbps / 512kbps**
Group video calling (7+ people)	4Mbps / 128kbps	8Mbps / 512kbps

As it can be seen, the minimum upload speed required for a standard definition video call doesn't depend on the number of members of a group. This is one of the features of the VoIP software when it acts as a client-server application – the video streams aren't uploaded to each client if there are more than one. They are uploaded to a server, only once, and each client is retrieving them from it.

Building up a conference video-call can prove very costly for the downlink, as the autolaboratory has to receive images from all participants in that group. That's why it is preferable to build the consulting group outside this environment which has a relatively small bandwidth, so that the VoIP connection with the *in-situ* personnel to take place in a one-to-one video connection.

Machine-to-machine (M2M) communication between remote users' computers and *in-situ* investigation devices takes place by the meaning of remote control freeware applications which allows the total control upon the applications running on computers deployed in the field. This allows operating the *in-situ* computers from distance, performing real time investigations just as a local operator.

Reported bandwidths usually involved in a session of remote control are estimated at an average of 60kb/s, when there is no action performed upon the remote panel (idle connection). Each action of a remote operator involves a data transfer between the connected computers. Depending on the exchanged volume of data, the delay introduced by the communication system varies with the uplink capabilities of the 3G router, i.e. with the type of connection established between the router and the radio network.

While the VoIP connection (M2M communication) is characterized by a relatively stable data traffic, the high dynamics of remote control connection, determined by periods of inactivity alternating with transfers of large amounts of data, results in a more difficult assessment of the required upload and download capabilities.

A rough estimation of the bandwidth which is necessary to be ensured by the Internet connection is presented in Table 2, according with different specific equipments.

Table 2

Estimated bandwidths when remote operation is in idle state

Equipment	Remote connection type	Estimated bandwidth	Notes
LIFS – Laser Induced Fluorescence Spectroscopy	Mixed - control, VoIP, video	0.05Mb/s + 0.13Mb/s +1.8Mb/s = **1.98Mb/s**	video definition 320x240 24bits @ 1fps, no compression scheme
LIBS-Laser Induced Breakdown Spectroscopy	Mixed - control, VoIP	0.05Mb/s + 0.13Mb/s = **0.18Mb/s**	
LDV – Laser Doppler	Mixed -	0.05Mb/s + 0.13Mb/s	

Vibrometry	control, VoIP	= **0.18Mb/s**	
Multispectral imaging	Mixed - control, VoIP, video	0.05Mb/s + 0.13Mb/s +1.8Mb/s = **1.98Mb/s**	video definition 320x240 24bits @ 1fps, no compression scheme
3D Laser Scanning	Mixed - control, VoIP, video	0.05Mb/s + 0.13Mb/s + 1.8Mb/s = **1.98Mb/s**	video definition 320x240 24bits @ 1fps, no compression scheme
Microclimate	Control and data	0.05Mb/s + 0.06Mb/s = **0.11Mb/s**	
Total		**6.41Mb/s**	Greater than the 3G router maximum upload bandwidth (5.7Mb/s)

VoIP: Voice-video connection between local operator and remote clients.
Control: remote control software applications. **Video**: process monitoring camera.
Data: transfer through other software applications (LabVIEW).

This assessment regards only the situation in which remote operator doesn't perform any action that implies transferring large quantities of data (opening remote documents or windows). The figures also refer to the situation in which all equipments are accessed simultaneously by remote users.

Values presented in Table 2 demonstrate that the images transfer without a compressing scheme has the largest contribution in bandwidth consumption (1.8Mb/s). That's why it become very clear that LabVIEW software applications involving *in-situ* image acquisition and transmission should make use of video codecs, in order to provide an economic mode for video streaming. As was previously shown, these codecs are able to produce compression rates of up to 80%. When it comes about images having a very static composition, as is the case of *in-situ* objects' monitoring, the data traffic necessary for video surveillance can be significantly lower than in the case of images having a high dynamic composition.

4. Video streaming - experimentally determined bit rates

As it was described in the previous chapter, the largest part of the data traffic is taken by the transmittal of video frames provided by the surveillance system which furnishes images of the investigation processes that are taking place in the field.

Transfer of images is a constant activity on the client-server chain and constitutes a constant background of the overall data traffic. This is also the case of the VoIP connections which ensure the permanent contact with local operators and technicians.

In Fig. 2 is presented a screenshot of the main page of the video web server which is installed in the autolaboratory.

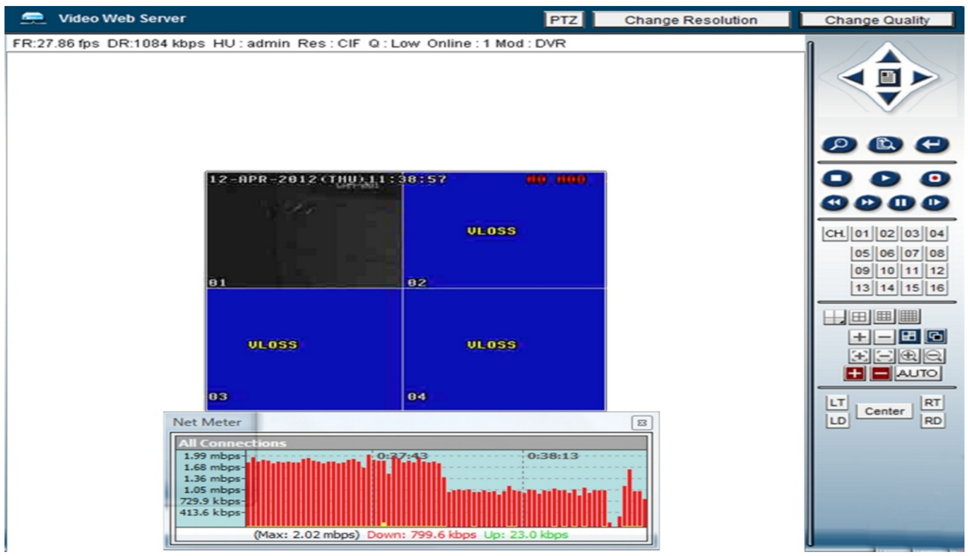

Fig. 2. Web page of the Video Web Server within the autolaboratory. The image quality is set to low.

The images have a low dynamic and brightness since it were taken inside the van while the back doors were closed (only one speed dome camera is installed and monitored on a single channel of the four-channels digital video recorder).

As it can be seen, the measured transmission frame-rate is 27fps (frames per second), which is taking place at a data rate of 1084kbps. For comparison, under the four-quadrant field is presented the data rate graph recorded with Net Meter, indicating approximately the same value.

The down step which is visible in the middle of the graph is indicating the moment at which the image quality was modified from high to low quality. As it can be seen, the bit rate was diminished from 1.8Mb/s to 1.08Mb/s, which represents 60% of the initial value.

In Fig. 3 is presented a black frame from the same camera, taken into darkness.

The measured frame rate is 23.64fps and the bit rate drops from 1.8Mb/s (for high quality image) to approximately 700kb/s (for low quality image).

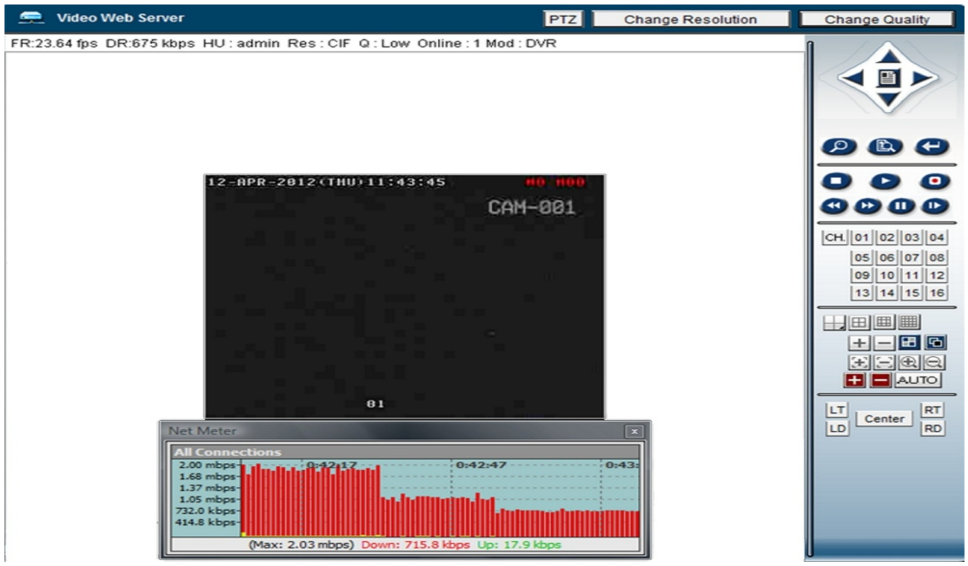

Fig. 3. Screenshot of Video Web Server's main page. The graph indicator is showing how the bit rate changes when the image quality is successively set to high, middle and low.

For this experiment a high speed dome camera model DSC-270Se was used. The resolution of this camera, according to manufacturer's technical specification, is 520TVL (TV lines) in color mode and the digital video recorder uses MPEG-4 encoding scheme.

Equation (3) presents the computation formula for the resolution, in pixels, of a PAL 4/3 camera, as it can be deducted:

$$ENP = 520TVL*4/3*576 \text{ pixels} = 399360 = 0.38 \text{ megapixels} \qquad (3),$$

where:

ENP - is the equivalent number of pixels;

520TVL - 520 TV lines, defined as the number of lines the image consists of, as technical specification of camera;

- 4/3 is the image aspect ratio (horizontal versus vertical);

- 576 is the number of vertical pixels in PAL encoding system.

In this case, ENP corresponds to a CCD matrix of approximately 720x540 pixels.

Fig. 4 presents a screenshot of the main page of the application running on the web server of the LIFS equipment [7].

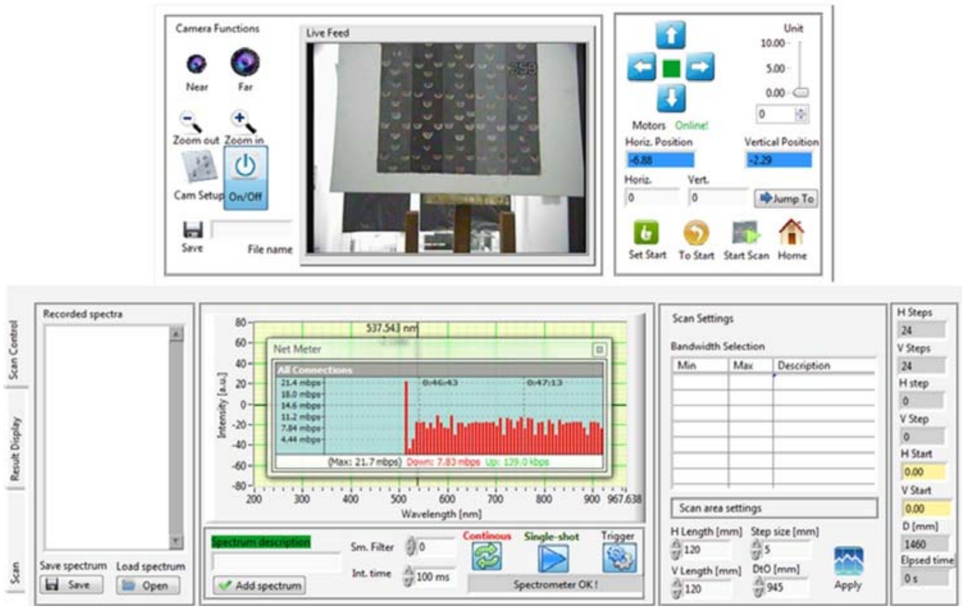

Fig. 4. A bit rate of 9Mb/s is recorded when the software application is controlled remotely by another computer within la internal network.

The graph in the middle represents the evolution of the data traffic recorded while remotely taking control over the software interface through the internal network within laboratory. Recorded bit rate is of about 9Mb/s and is due to streaming life images with a resolution of 320x240 pixels and a color depth of 24 bits. These values produce bitmaps of 1,843,200 bits (320x240x24).

At a frame rate of 5fps, established through the acquisition software, we find that the application transmits 1.8Mb x 5Hz, which it is a value of 9Mb/s, confirmed by measured values.

Since there is no compression scheme used, the traffic doesn't depend on image's composition, as is illustrated by Fig. 5, where the acquired image is completely black. The recorded traffic presents the same value for the bit rate.

Is necessary to normalize the resolution and frame rate of bitmap images to make a comparison between the two examples (bitmap images and MPEG-4 images transmittal). The resolution ratio between a bitmap image of 320x240 pixels and a MPEG-4 image of 720x540 pixels is given by equation (4):

$$Rr = 720x540 / 320x240 = 5 \quad (4),$$

where Rr represents the resolution ratio.

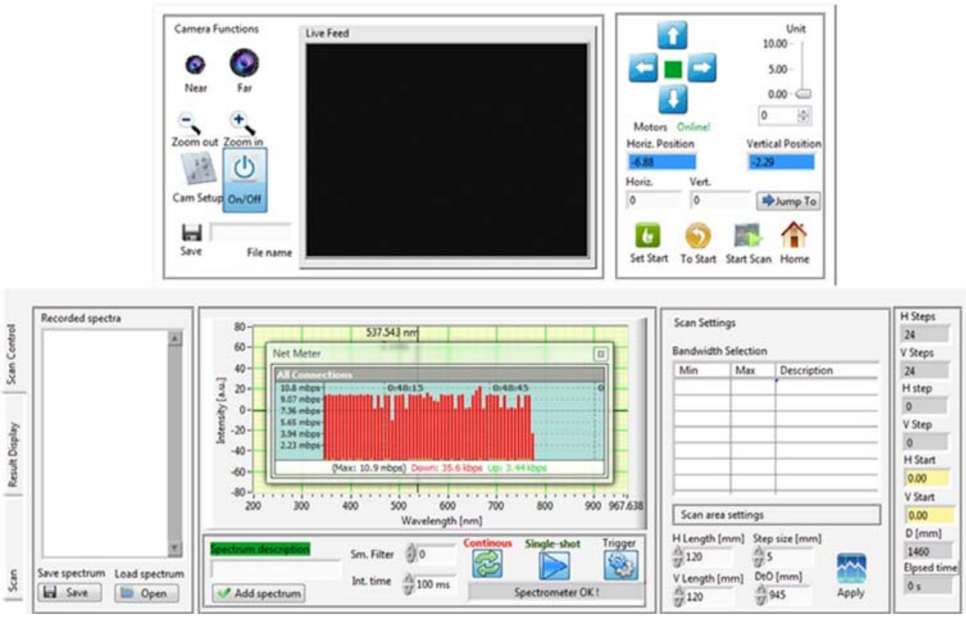

Fig. 5. The traffic recorded when the acquired image is completely black. Sudden decreasing of the traffic is registered when the remote computer ceases to control the application.

The frame rate ratio is given by equation (5):

$$FRr = 25fps / 5 fps = 5 \qquad (5),$$

where FRr is the frame rate ratio.

It is important to notice that if we would transmit MPEG-4 encoded streams with high quality (1.8Mb/s), then images of 320x240 pixels at 5fps (as is the case of LIFS equipment) would take only 0.072Mb/s, as it is described by equation (6):

$$\frac{1.8Mb/s}{Rr*FRr} = 0.072Mb/s \qquad (6),$$

Replacing the value of 1.8Mb/s which corresponds to video streaming, in Table 2, we obtain a necessary bandwidth of 1.22Mb/s, which is much lower than previous value of 6.41Mb/s with a substantially improved frame rate of 5fps instead of 1fps.

This upload speed is easily achievable when the 3G router is connected in HSPA mode, as it is demonstrated by Figure 2 and Figure 3, where the graph indicator of Net Meter indicates download speeds of 1.8Mb/s at the remote computer side.

Taking these into account, Figure 6 presents a schematic representation of the communication infrastructure and internal organization of the autolaboratory, as a design in which external users from academic and scientific media can access the mobile platform, assisting at or developing their own experiments.

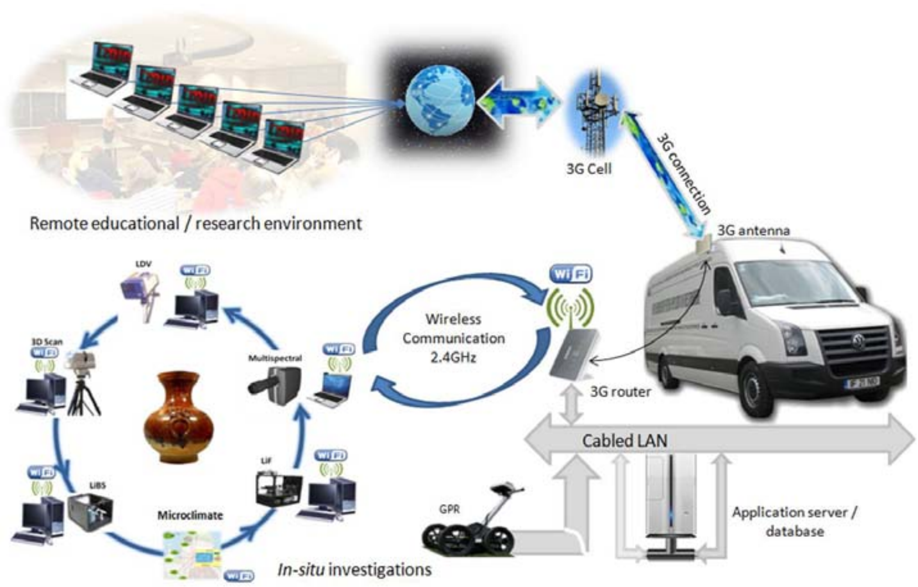

Fig. 6. Communication structure and organization scheme of the autolaboratory. Schematic representation of the communication chain between remote users and in-situ equipments and operators.

5. Conclusion

The paper presents a solution for remote data management and communication applied in the case of a Internet connection established between a group of remote users and the autolaboratory situated in the field. The described solution takes into account some aspects regarding achievable Internet connection capabilities of the mobile platform and assesses necessary bandwidths for a comfortable remote operation, characterized by reduced time lags.

Presented solution also envisages and is suitable for similar types of applications that involves remote operation of devices deployed in the field.

The most convenient and affordable way to connect the autolaboratory to Internet is the terrestrial radio network offered by internet services providers operating within cellular telephony networks.

However a good connection is required, preferable in HSPA mode, if equipments within autolaboratory have to be operated simultaneously. Otherwise, slower connections like 3G are yet usable.

The paper also presents a concept regarding internal organization of equipments within a local area network to which they can be connected either by cable or wirelessly, a solution that offers a better mobility in the field.

Remote conferences between users belonging to academic and scientific media and *in-situ* operators can be opened by using VoIP technology and control of the *in-situ* computers can be taken from distance using wide spread, free remote control software applications.

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