IDOLO: Multimedia Data Deployment on SCADA Systems

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***Abstract*--IDOLO project was born with the objective of adding audiovisual information to the usually text-based Human-Machine Interfaces (HMI) used on Supervisory Control And Data Acquisition (SCADA) systems. This is not a simple task, as SCADA systems have traditionally been based on proprietary, low transmission speed networks, due to the special requirements that such systems impose in terms of network reliability and timing requirements.**

Within this paper we describe our efforts on the design, implementation and deployment of a networked computer system that adds multimedia information to the usually text-based SCADA/HMI systems. IDOLO system is based on well-known hardware and software solutions, such as Ethernet networks or MPEG codecs, resulting in a flexible and expandable system that has succesfully been deployed on a real electrical facility.

Index Terms--**Multimedia systems, SCADA systems.**

I. Introduction

The main goal of every SCADA [1] system is the remote supervision and control of devices -mostly sensors and actuators- located at remote facilities. Information provided by these devices, in example the measurement of the current in a power line is short, not longer than some dozens of bytes. As a result from this, the traditionally used technologies are still suitable for the delivery of devices data, and probably will be in the future.

However, transmission and networking technologies are not the only fields that have dramatically been improved over the last years. Multimedia compression techniques have also evolved in such a way that digital video and audio can now be processed by cheap PCs, obtaining good quality displays using relative low bit rates. Modern codecs such as MPEG-4 [2] allow compressing high resolution video signals so they can be meaningfully represented using less than 1 Mbps.

Human Machine Interfaces, used to easier the management of the SCADA network operators, typically display the status data as text strings, and in some cases, in the form of symbols representing device state.

Complementing that information with video or audio can be of much help when operating wide SCADA networks, where there is usually no staff at remote stations.

Security surveillance or videoconference, are also another bonus features multimedia information could bring to SCADA systems.

II. About Multimedia Data Processing

There are many aspects to be considered when dealing with computer multimedia systems:

- Images and sound coming from video cameras and microphones needs to be digitalized so computers can handle them. Modern cameras, such as Digital Video Cameras (DV-CAM), already provide the video signal in digital form, but most other video devices need a previous step called capturing to be performed before any processing is done. Typically, frame grabbers do video capturing and audio is captured using sound cards, which have all the needed circuitry such as A/D converters.
- Video data, and to a lesser extent audio data, when on raw digitized form, take a huge amount of space. A simple 24-bit 640x480 video frame needs 921600 bytes to be stored, so to keep data size on a practical level, multimedia data needs to be compressed. Multimedia data compression requires high processor resources, so powerful CPUs and fast memory sub-systems are required to do the needed processing. There are plenty of coders/decoders (a.k.a. codecs), from which we can highlight MJPEG and MPEG-4 for video compression, or MP3 for audio compression.
- Sending multimedia data over computer networks is done by a process called streaming. Streaming consists in taking compressed video and audio data and chopping it into smaller blocks, keeping at the same time synchronization between audio and video. But even when data is compressed, it still requires high bandwidth links to be transmitted. A 640x480 pixels stream encoded with MJPEG codec at a frame rate of 25 fps requires about 1,5 Mbps, whilst the same stream encoded with MPEG-4 codec wastes about 512Kbps of bandwidth resources.

III. Multimedia on SCADA Systems

Better than talking about integrating multimedia data into SCADA systems, we should think about integrating SCADA data into modern networked systems.

Typical transmission links and protocols used on SCADA networks do not fulfill the bandwidth requirements multimedia data deployment impose, as data acquired from SCADA devices are usually transmitted over low-bandwidth links using serial protocols.

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Another important key factor is that temporal requirements on the reception of the acquired data are very tight on SCADA systems; cycle time on SCADA buses generally ranges between 10 ms and 100 ms. Going further, transmission reliability is also very important as loss of data might cause a big impact to the system integrity.

We have successfully injected SCADA data into an Ethernet system [3], using a custom SCADA bridge. Data transmitted using IEC870 [4] protocol from a Multitrans PLC device -which gives data about the voltage and intensity of a powerline among other features- is injected into an Ethernet network using bidirectional serial-to-Ethernet converters.

The converter we used, named IS-Server device, takes serial data from the Multitrans device and converts it into TCP packets, sending them to a predefined IP network address. If control system needs to receive data in its original serial form, the inverse process may be applied using another IS-Server device.

In our tests status data periodically polled from Multitrans device traveled between two Ethernet-based LANs connected via a 100Mbps fiber optic link, resulting in the SCADA data being received in less than 10 ms even when a raw multimedia stream, which needed nearly all the available bandwidth, was also sharing the fiber optic link.

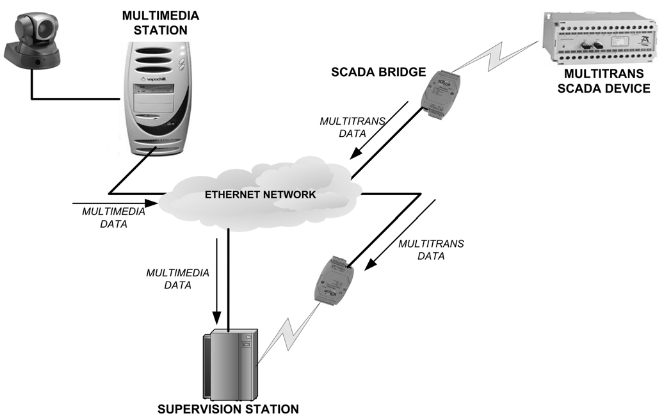

Fig. 1. Ethernet SCADA bridge.

As proved above, from a temporal approach, sharing the physical medium between SCADA and multimedia data is possible in Ethernet networks, but transmission reliability must also be considered. Ethernet hub devices use CSMA-based medium sharing techniques [5], which can lead to packet loss in a high traffic scenario, due to packet collision. Therefore, switches should be the starting point on the design of any multimedia SCADA system.

Network management techniques such as Quality of Service [6] might also be used to ensure SCADA data always gets the bandwidth it needs. QoS allows packet prioritization and bandwidth provision, based on one or more factors, such as the IP address of the sender.

IV. Analysis of System Elements

A.. Network Components andProtocols

Apart from the mentioned cautions to be considered about packet collision introduced by network hubs, it's important to know that typical commercial network products are not adequate to work on harsh conditions present on factories or remote electrical facilities.

High temperature and exposure to electric-magnetic and/or radio frequency disturbances could cause dysfunctions to Ethernet devices. Although the effect of perturbations can be partially solved using fiber optic links, chasing of common commercial devices is not usually adequate to work on industrial environments. To avoid this drawback, network devices built under Industrial Ethernet/Ethernet-IP [7] standard can be used as they have adequate chasing and components that allow them to work on harsh conditions.

In respect to network protocols, followingly we highlight most important facts related to each network level:

1) Physical Layer.

In theory, any physical medium is adequate for the transmission of SCADA’s data, but on tough environments such as is the case of electrical substations, shielded twister pair, fiber optic or even the electrical lines themselves –using power-line communications- is a must.

2) Data-link Layer.

Usage of widespread, standardized technologies means lower maintenance and adaptation costs as today’s most common data-link devices are Ethernet-based, which are suitable for our purpose as far as CSMA/CD is not used. Another important feature is SCADA devices lack of MAC addresses, which are needed by Ethernet network devices to communicate between them. This means SCADA bridges must add an unique MAC address to each one of the SCADA elements connected to the network.

3) Network Layer.

IP protocol is the clear winner, as it’s by far the most common network-level protocol.

There’s one aspect affecting not only this layer but also data-link layer, and both distributed and master-slave systems. It consists in that although communication from slave PLC devices to master stations is achieved without regards to the underneath SCADA protocol, bridges sending data from master stations need a mechanism to know the slave station they are trying to communicate with, in order to forward data to the correct MAC/IP address. This means SCADA bridges need to be protocol-dependent.

4) Transport Layer.

TCP protocol is well suited for both the sending of SCADA and multimedia data. However, packets can be received in a disordered sequence, so there’s the risk some data is received too late on high-traffic conditions. On the contrary, UDP protocol is not recommended for encapsulating SCADA packets, as it does not implement any mechanism to ensure data reception.

B. Audio and Video Acquisition Devices

There are a wide variety of video cameras on the market. Some of them already have digital outputs, so additional capturing hardware is not necessary. We have worked with 3 types of cameras during the development of IDOLO system:

1) *Webcams.*

These are the usual PC-based cameras. They have USB connectors, so they don't need additional capturing hardware; but they still need additional compression and streaming software.

2) *PTZ Cameras.*

Motorized cameras with analog input. They need additional capturing hardware, as well as additional compression and streaming software.

3) *Network Cameras.*

They don't need any additional hardware or software as they already provide a compressed streamed output. Some models also provide pan, tilt and zoom functionality.

TABLE I
COMPARISON OF CAMERAS FEATURES

Type	Output	Capture	Compression	Storage	Streaming
Webcam	USB	Yes	No	No	No
Sony PTZ	Analog	No	No	No	No
Network cameras	10-base-T	Yes	Yes	External	Yes

C. Encoders

We'll define encoders as those systems capable of capturing and compressing audiovisual information, pushing that compressed data to a network or to mass-storage devices. That's it; an encoder is a system that captures, compresses, streams and/or stores multimedia data.

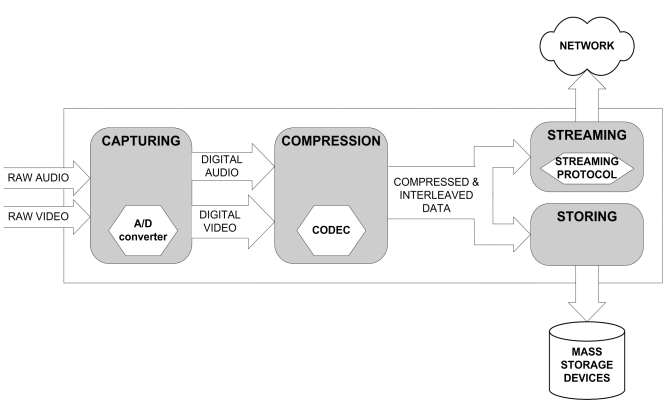

Fig. 2. Encoder structure.

There exists PC-based encoder software that does some or even all of the needed steps; there's also specialized, independent hardware such as network cameras that make the entire job by themselves.

D. Codecs

Two codecs have been used in IDOLO system: MPEG-4 and MJPEG.

MPEG-4 has the drawback of introducing a noticable delay in the reception of streamed content. This delay is introduced by the intermediary buffers needed by both the encoder and the player applications to handle inter-frame (temporal) compression, and results in video being received about a couple of seconds later than when the movement was done.

MJPEG-based solutions, on the contrary, remove the need of intermediary buffers, as they only implement intra-frame (spatial) compression, with the cost of a lesser effective compression efficiency.

D. SCADA/HMI Software

Integration of IDOLO system interface into existing SCADA/HMI systems is another challenge we had to resolve. Most HMI software suites are closed systems where integration of extra functionality can only be done by the HMI system developers.

However, some modern Windows-based HMI suites allow the integration of external components by the usage of ActiveX technology. We have successfully integrated IDOLO system's web interface into Intellution iFIX HMI suite by using Internet Explorer's capability of being embedded into ActiveX containers. IDOLO system software components, such as a PTZ joystick controller or multimedia players also make use of ActiveX technology to allow their integration into third-party applications.

V. IDOLO SYSTEM STRUCTURE

A. Interface

We have built IDOLO's interface as a web-based software system, supported by a database system, which manages all needed system configuration and allow operators to easily have access to all multimedia information of the SCADA system.

Being web-based means it can be independently run from an existing SCADA/HMI system and at the same time it can be integrated into HMI systems supporting web navigation. HMI software supporting ActiveX technology can easily integrate IDOLO software system via an embedded ActiveX web browser.

Furthermore, some web browsers such as Internet Explorer also support ActiveX components; so software components specific OF IDOLO system have been developed as ActiveX controls.

IDOLO navigation system has been developed using PHP programming language on the server side, and Javascript on the client side. PHP is used to control the content and layout of served HTML pages and to serve as the interface between IDOLO system and a MySQL database server that holds all system configurations, such as data about cameras or the design of multimedia synoptics of each station. Using Javascript permits interfacing with web-browser, allowing IDOLO system to know about user input events (e.g. mouse clicks) or controlling specific browser properties.

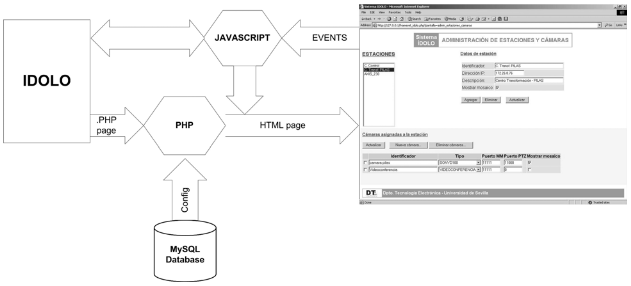

Fig. 3. Web interface components.

B. Camera management

From the logical point of view, IDOLO system is formed by 2 elements: stations and cameras. It's hierchically organised whereby stations own one or more cameras. We have worked with 3 types of cameras, each one with some special features, which forces using different approaches to manage each camera type.

First, network cameras, which do not include internal storage systems, need an external system to store its video. The network camera we have choosen, AXIS 230, uses MJPEG codec, which is no more than a sequence of JPEG images. MJPEG is not an efficient video codec as it only performs spatial compression (based on Discrete Cosine Transformation), as opposed to MPEG-4 that performs both spatial and inter-frame compression. As it needs an external FTP server with enough storage space to stock the video, this together can suppose an excessive use of network bandwidth.

Webcams and analog cameras need dedicated PCs to perform the needed compression and streaming. We have chosen Windows Media software platform to deal with these processes, which allows full control over nearly all aspects regarding the previously mentioned procedures.

- Windows Media Encoder is a software component that takes video and audio from USB cameras and frame grabbers and compresses it with Windows Media codecs, variants of MPEG-4 codec in the case of video and MP3 in the case of audio. It also allows storing compressed content on the fly on both local and remote storage.

- Although WME also allows streaming using HTTP/TCP protocols, Windows Media Services is a specialized component that takes data compressed with WME and pushes it to network using RTSP/UDP protocols. Apart from using more efficient network protocols for streaming, WMS is the needed solution for allowing external stations to receive multimedia content from WME encoders, in case IP addresses of encoder stations are inside the local scope, as shown on Fig. 4.

C. Multimedia synoptics

Synoptics are the common way HMI systems use to show, in a single screen, all representative data about SCADA elements. IDOLO system takes this approach and adapts it to the multimedia field (fig.5):

- Showing video windows and audio coming from cameras located at a given station.

- Having graphics of all representative elements in a station, which, when clicked, command PTZ cameras to move to a preset position so it focus the selected element.

- Allows the activation of manual control on PTZ cameras, being able to control them using the mouse or even a joystick.

The concept of multimedia synoptics is also a solution to the inherent delay introduced by MPEG-family codecs, which makes manual control of PTZ devices a bit confusing as image runs late in respect to camera movements.

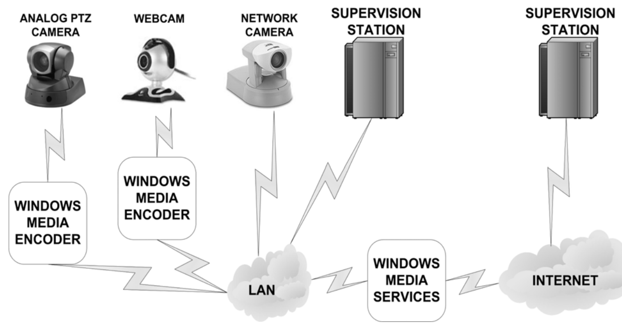

Fig. 4. Streaming content outside the intranet.

VI. Deployment on an Electrical Facility

Final goal of IDOLO project was the integration of our system into a real, working SCADA system. To this purpose, we have got the cooperation of Medina Garvey electrical facility, a regional electrical provider located in Seville.

Existing facilities owned by Medina Garvey are controlled and supervised using SCADA hardware and software developed by Team Arteche. An example of those SCADA components is the Multitrans device we used in our integration tests.

As we didn't want to compromise the integrity of existing system, we decided to use separate links for sending multimedia and SCADA information, from remote stations to supervision station. Modern facilities in Medina Garvey are equipped with fiber optic links to communicate with supervision station, so we have used spare fiber cabling for our purpose. These fiber optic links are more than addequate for transmitting high-quality multimedia streams.

There are some older facilities that do not use such high-speed links. In such a case, they use serial radio links to transmit SCADA status information, which do not have enough bandwidth to send multimedia information over them. But these facilities have also been equipped with telephonic lines, so we have used ADSL technology for sending our multimedia streams. However, usage of ADSL limits the transmission to few, low-quality streams; we have successfully tested the transmission of one 512 Kbps stream, and alternatively, two 256 Kbps streams.

In respect to the SCADA/HMI system used by Medina Garvey, SIPCON HMI system, it's a proprietary, MS-DOS based system, which does not allow the integration of external components. Therefore, IDOLO software has been deployed separately, using a PC with Internet Information Services web-server to provide web content to the intranet.

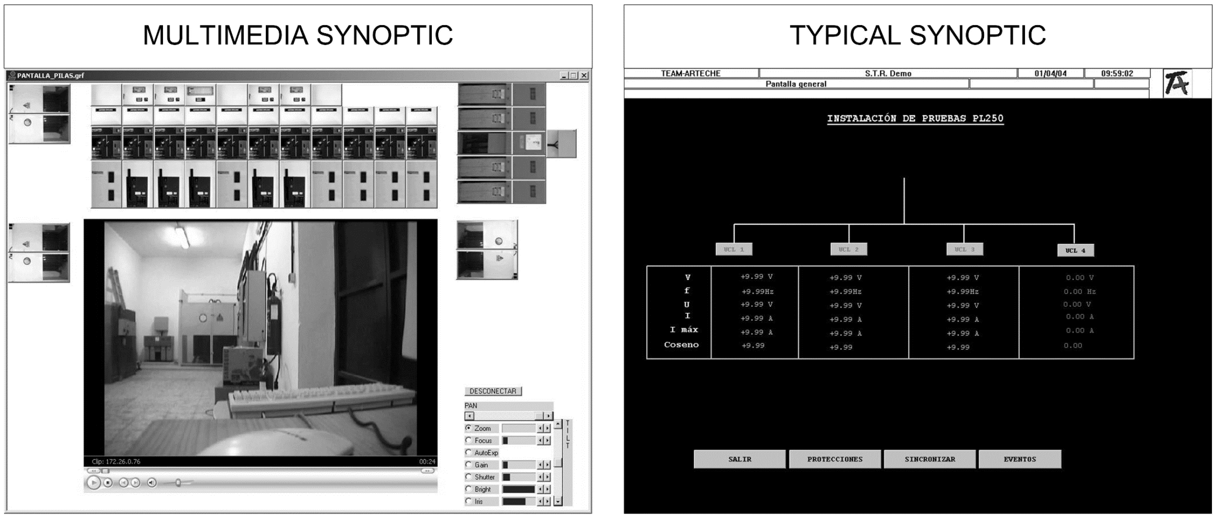

Fig. 5. Screenshots comparing multimedia synoptics and classic synoptics.

VII. Conclussions

Within this paper, we have described our solution for integrating multimedia information into existing SCADA systems.

This integration is achieved thanks to a careful network design and the usage of modern software technologies. Network core of IDOLO system is based on Ethernet standard, which means having a reliable and expandable network with the advantage of low maintance costs. System interface is web-based, allowing users from both inside and outside the intranet to access the system; it also makes use of ActiveX components, which expands system integration and expansion capabilities.

IDOLO system has been successfully deployed on a real electrical facility. Operators can now take profit of the advantages introduced by the displaying of video and audio signals coming from remote stations. They can now get live views of maintenance works, or they can inspect devices located on remote facilities, from the supervision station or even from their home though internet.

VIII. References

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IX. Acknowledgements

The work described in this paper has been funded by the Ministerio de Ciencia y Tecnología through the project reference number TIC2000-0367-P4-02.

We'd also like to thank ISIS Engineering (Seville) for providing us with IS-SERVER prototypes, and Medina-Garvey electrical company for making use of their facilities.

X. Biographies

J.I. Escudero received his Physics degree in 1979 and his Doctorate in Physics in 1995 from the University of Seville (Spain).

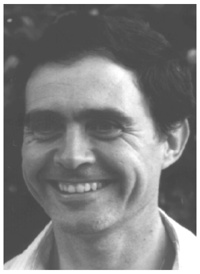
He has held several teaching positions. He has been Professor of electronic engineering at the University of Seville since 1989. Dr. Escudero has focused his research activity on the study of computer network performance, power systems telecontrol and the use of multimedia in power systems control.

J.A. Rodríguez received his degree in Computer Engineering in 2003 from the University of Seville (Spain). At present he is working in several projects about multimedia in the operation of large industrial networks.

His principal study is focused on the use of multimedia in power systems telecommunication networks.

M. C. Romero received her degree in Computer Engineering in 1999 from the University of Seville (Spain). At present she is working in her Ph. D. thesis in Multimedia Control of Power Systems.

Since 1999 she has worked in several research projects focused on telecommunications network management and power systems telecontrol at the University of Seville. In 2001 she became Associate Professor and began her teaching work in the School of Computer Engineering, University of Seville.



J. Luque received his degree in Industrial Engineering in 1980 and his Doctorate in Industrial Engineering in 1986 from the University of Seville (Spain).

Since 1980, he has worked for several companies in the area of SCADA systems for electrical networks, participating in some of the primary EMS projects in Spain. He is currently a Professor of electronic engineering at the University in Seville, and he is a member of the IEEE.