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**MANAGEMENT OF DISTRIBUTED MEASUREMENT SYSTEMS  
BASED ON ABSTRACT CLIENT-SERVER PARADIGMS**

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# Management of Distributed Measurement Systems Based on Abstract Client-Server Paradigms

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**Abstract** – *This paper describes in detail a Java-based, client-server architecture specifically conceived to allow a flexible control of remote devices. The main attributes of the proposed solution are portability and flexibility. The former feature is assured by the employment of the TCP/IP protocol suite and by the Java language properties. The latter is due to the high level of abstraction of the system implementation, that addresses multi-user issues and a wide range of possible applications with a high code reusability. In particular, the proposed architecture can be easily upgraded so as to fit different kinds of devices, by simply adding a limited amount of code on the server-side of the overall system.*

**Keywords** – *Internet, Java, distributed measurement system, client-server architecture, remote calibration.*

## I. INTRODUCTION

In recent years, the growing demand for improved interoperability between electronic instruments, the increase in PC computing and input/output capabilities along with the diffusion of standard buses specifications (e.g. IEEE 488, IEEE 1394, PCI/PXI and VME/VXI) and network protocols, have favoured the development of software tools oriented to the implementation of distributed control architectures. Such tools represent enabling technologies for the development of home automation networks [1], human-robot interactive applications [2]-[5], real-time collaborative telemedicine systems [6] and, more generally, distributed measurement systems (DMS) both for educational and industrial purposes [7]-[9]. Unfortunately, many of the commercially available software tools devoted to Virtual Instrument (VI) implementation (e.g. Labview, Lab Windows and HPVVEE) often require specific applications to be installed on client computers [10]. Moreover, since they are based on proprietary technologies, remote control applications can not be freely distributed or easily extended. Conversely, common object remote brokers and interfaces have been defined to create extensible and distributed programming environments. By using Corba technology, for instance, each application is the result of a collaboration between several objects distributed over communicating networks and coded using various languages. Thus, new programs can easily and quickly be extended to address dedicated purposes. A similar goal can also be reached with object oriented languages, like Java and C++, without modifying the original structure of the source code [11]. This result is achieved by using abstract classes and by loading dynamically software libraries such as *dynamic link libraries* (dll) on Windows platforms or *shared object* (so) libraries under Unix.

Even if many solutions have been proposed on this topic, a certain lack of detailed low-level descriptions of possible implementations has been observed in literature. So one of the aim of this paper is to give a full description of a highly abstract Java-based client-server architecture that is able to control measurement systems remotely. Unlike other robust, highly distributed multi-server architectures [8][10][12], the solution presented in this paper focuses mainly on the optimization of the communication systems between multiple clients and a single server, whose high flexibility and ease of reconfiguration has been considered very important for the development of future multi-layered distributed applications.

In following sections, at first the overall operating environment is described and the design choices are explained. Then, it is shown that the integration of new instrumentation and PC-cards, such as CAN or IEEE 488 controllers, can be accomplished without modifying the code of the client-server architecture. Finally, an example of system implementation devoted to remote calibration purposes is presented.

## II. DESCRIPTION OF THE DISTRIBUTED MEASUREMENT SYSTEM

Because of the rapid evolution of information exchange standards, any newly devised architecture for remotely controlling instrumentation should include enough features to accommodate actual hardware and software specifications, possibly anticipating future technological developments. This is one of the reasons why the proposed system has been designed to be highly abstract, easily extensible and user-friendly.

The system architecture is shown in Fig. 1. It consists of a group of distributed client-server applications that can be upgraded to control general-purpose instrumentation over the Internet. These instruments are either plugged directly into PCs (e.g. PCI data acquisition boards) or interfaced via a bus controller (e.g., IEEE 488 and IEEE 1394 cards). Security issues related to client-server communications have been addressed by using the Secure Socket Layer (SSL) protocol for each connection established between client and server ports. Obviously, the server is protected by a password. The access and the possible sharing of the available resources are managed using the multithreading approach. When a user requests the execution of any control operation, the server application runs a new dedicated thread. Since more than one thread can be run and processed independently, the system

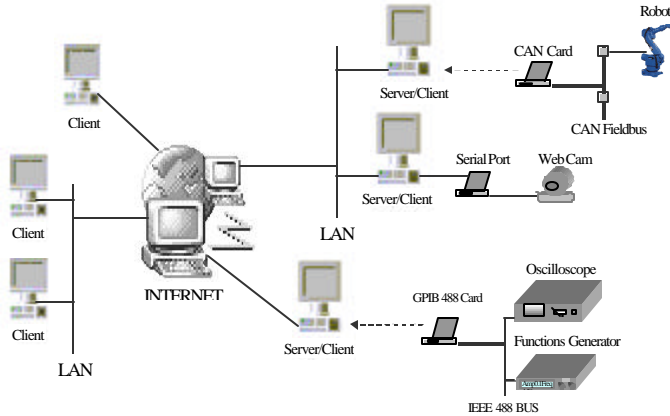


Fig. 1. Extensible distributed measurement system.

allows the execution of multiple operations at the same time. A portion of the server application has been conceived to engage, release and share the requested resources and to manage simultaneous accesses. The client-side application is started automatically when a user connects to the server homepage using a Java-enabled browser. Users are presented with a graphical user interface (GUI) showing the list of controllable interface cards and instruments, directly installed on the server. Moreover, if a standard bus controller (e.g. IEEE 488-PCI bus interfaces) is chosen, an additional search is performed to find devices connected to the bus. A list of all resources is shown on a graphical panel, enabling selection of a specific device. Then, by using secure socket connections and the TCP/IP communication protocol, information can be exchanged with the server unit (instrument control commands, parameters and reports). Finally, obtained measurement data can be saved locally or visualized on the screen. Notice that, the use of full Java-based graphical panels has been preferred over servlet technology, because it reduces the loading time of GUI, thus improving system performance.

Unlike other valuable Java-based multithreading solutions that need the insertion of several Java server classes to manage any instrument newly connected to the server [13], the most important feature of the proposed architecture is its easy extensibility. In fact it is possible to manage new cards and instruments installed on a server unit without recompiling or modifying any code component. It is only necessary to add a limited portion of upgrading code on the server. This operation is feasible either locally or remotely. In the following subsections the chosen programming tools will be described, along with a functional and temporal analysis of the proposed architecture.

#### A. Software Tools

As mentioned in the introduction, several languages are used to implement distributed control systems. The architecture described in this paper has been coded using the Java and C

languages. Java simplifies the development of data exchange mechanisms between client and server systems, by offering graphical user interfaces and client-server communication methods based on socket connections and applet executions. Moreover, the Java Secure Socket Extension (JSSE) set of packages implements a Java version of SSL (Secure Sockets Layer) and TLS (Transport Layer Security) protocols and includes functionality for data encryption, server authentication, message integrity, and optional client authentication.

On the other hand, C is the language most frequently used to realize drivers and libraries for the low-level control of devices at the highest execution speed. In order to translate programming elements from Java to C, the Java Native Interface (JNI) and native methods have been employed [14]. However, native methods demand knowledge of both Java and C languages. Better results and lower development efforts could have been achieved using Microsoft Visual Java [13]. However this product was recently withdrawn from market. To describe the system at the architectural level, the unified modeling language (UML) has been employed. This language is useful to describe organizational and technical systems. To this purpose it employs 12 types of diagrams divided into 3 main categories: diagrams to model static application structures, diagrams to represent different aspects of dynamic behaviors and diagrams to organize and manage the application modules [15].

#### B. Functional Description of the Client-Server Architecture

The architecture is composed of a client, a server and an Internet units. The implementation code is divided in 2 parts: an Abstract Client-Server Architecture (ACSA) that represents the permanent part of the code and an upgrading code portion inserted for expansion purposes. The working principle of the overall architecture is based on 3 main functions responsible for client-server communications, abstract management of the available physical resources and upgrading operations. In order to describe the functional and time relations between objects and classes of the ACSA architecture and the upgrading code, a UML collaboration diagram has been employed, that is shown in Fig. 2. In this diagram users, developers and managers are represented as 3 actors that allow data exchange between client and server for remote automation purposes. The sequence of operations is as follows. The *system manager actor* or the server operating system starts the server application asynchronously by opening the *AppletServer.htm* file. This file contains the number of the server port accepting connections and a list of the available resources. This data is essential to access and to share over the Internet the devices connected to the server. Then, *Appletserver.htm* loads an applet that reads the information stored in the html file through the *getParameter()* method. Finally, the applet starts the *MultiThreading* class that allows the server to enter a waiting state, expecting connection requests.

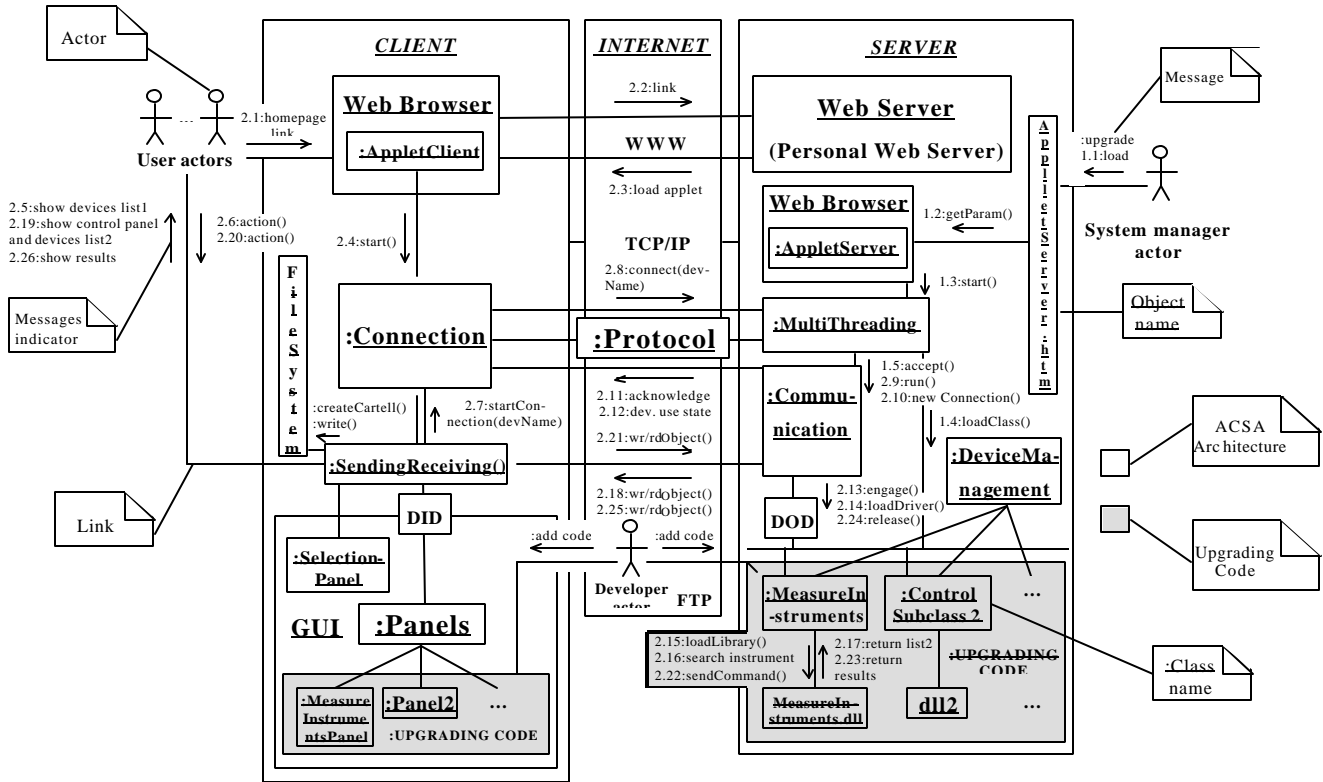


Fig. 2. UML collaboration diagram of the client-server architecture.

The *user actors* load the client application by opening the server homepage and executing the *AppletClient* applet. They can establish a link with the server by means of the *Connection* class which generates a socket connection to *MultiThreading*. The connection or the disconnection to or from the server, can be carried out by the *user actors* through a dedicated menu in several graphical panels. They are used to choose the instruments, to insert control commands and parameters, and to visualize the responses from the server.

If *MultiThreading* accepts the connection request, it starts the *Communication* class in a dedicated thread and waits for a new request. In this way, more than one *user actor* can have access simultaneously to the server system and control one of the available instruments. In order to allow data exchange between client and server connection sockets, object input/output streams are defined. Initially, such streams are used by the server to send acknowledge messages concerning the connection state; then, they are used by the client to receive the list of the available resources. The selection of resources is performed in 2 stages: at first, *user actors* have to choose one of the devices or controllers in the received list shown through *SelectionPanel*. Then, if a controller for a particular input/output standard bus is chosen (e.g., IEEE 488, IEEE 1394), a search for devices physically connected to the bus is started automatically. This mechanism is carried out by a native method implemented in the driver of the bus controller. After completing the first selection stage, *Connection*

sends to the *Communication* class the name of the chosen device and waits for answers about its availability. The rules allowing the dialog between *Connection* and *Communication* are defined in the *Protocol* class. If the requested resource is available, the corresponding panel, subclass of *Panels*, will be shown to the *User actors*. Thus, they can select one of the instruments found in the second search stage, and can insert measurement data and control commands in the panel fields. The user requests are sent to the server through the *SendingReceiving* class. This operation employs an input serializable object of the *DeviceInputData* (DID) class whose attributes are suitable to represent all kinds of device input data. Finally, *Communication* and the subclasses of *DeviceManagement*, transfer to the instruments the requests received from the client and return measurement results, if available. This occurs through an output serializable object of the *DeviceOutputData* (DOD) class.

For each new resource installed on the server, the *developer actor* has to upgrade the system by adding new management code (highlighted in grey in Fig. 2). In particular, a new subclass of *DeviceManagement* has to be implemented, as well as one or more dll drivers for the low-level control of the device and a new dedicated GUI panel. Moreover, when the new card or instrument is connected to the server, the *manager actor* has to upgrade the parameters list in the *AppletServer.htm* file.

### III. ABSTRACT MANAGEMENT OF THE AVAILABLE RESOURCES

The easy extensibility of the system depends on the abstraction features of the ACSA. This has been achieved on the basis of 3 design choices:

- the declaration of device-independent attributes in the DID and DOD classes;
- the dynamic loading, on the client-side, of the control panels inheriting attributes from the *Panels* superclass;

the dynamic loading, on the server-side, of the device specific subclasses inheriting methods from *DeviceManagement*.

The two former features in the list allow to exchange management and measurement data through a common interface, regardless of the kind of controlled devices. This means that, even if a different virtual front panel is employed for each instrument, control messages, either written in text fields or set by clicking on checkboxes, are encapsulated in a unique data record before being transferred. A dual mechanism is used to return measurement results to the client. All of the fields of these records are declared inside the *Panels* superclass as shown in Fig. 3(a), in which a UML class diagram describes the hierarchic relationship between *Panels* and its device-dependent subclasses.

As regards the third feature in the list, *DeviceManagement* allows the management of any controllable resource. This is accomplished by declaring abstract methods such as *shareable()*, *engaged()*, *engage()*, *release()* and *loadDriver(object: Object)*. As shown by the UML class diagram plotted in fig. 3(b), all of these methods are implemented in the *DeviceManagement* subclasses whose structure depends on the different characteristics of devices connected to the server. The device-dependent methods, unknown to the ACSA, are called

by the *Communication* class through an instance variable of *DeviceManagement*.

Methods *shareable()* and *engaged()* are devoted to detect the device availability following a specific user request. Instead, *engage()* and *release()* allow to employ such device if it is available and to release it when the user stops controlling the resource. Finally, *loadDriver(object)* loads dynamically the dll or so drivers, containing the C native methods necessary to control the requested instrument.

### IV. AN EXPERIMENT OF REMOTE CALIBRATION

An application of the ACSA architecture has been developed to carry out remotely calibration procedures [16] on some measurement instruments located in the laboratories at University of Perugia. In particular, an IEEE 488 card has been installed on the server-side of the system to allow the remote calibration of a Hewlett Packard 3440A multimeter and a Hewlett Packard 54603B oscilloscope by means of a Fluke 5500A multifunction calibrator. For this purpose, the upgrading code of the client-server architecture needed the implementation of three main software units: a subclass of the *DeviceManagement* class, a C programme and a subclass of the *Panels* class. In the first unit the *loadDriver* method call two native methods, implemented in the second unit, that allow to look for all measurement instruments connected to the IEEE 488 card and to carry out the calibration procedures. The method that execute this last operation must receive in input some calibration data specified from the remote user of the system on the client-side. This data consist of the name of the instrument chosen to be calibrate (Device Under Calibration (DUC)), the kind of the measurements that

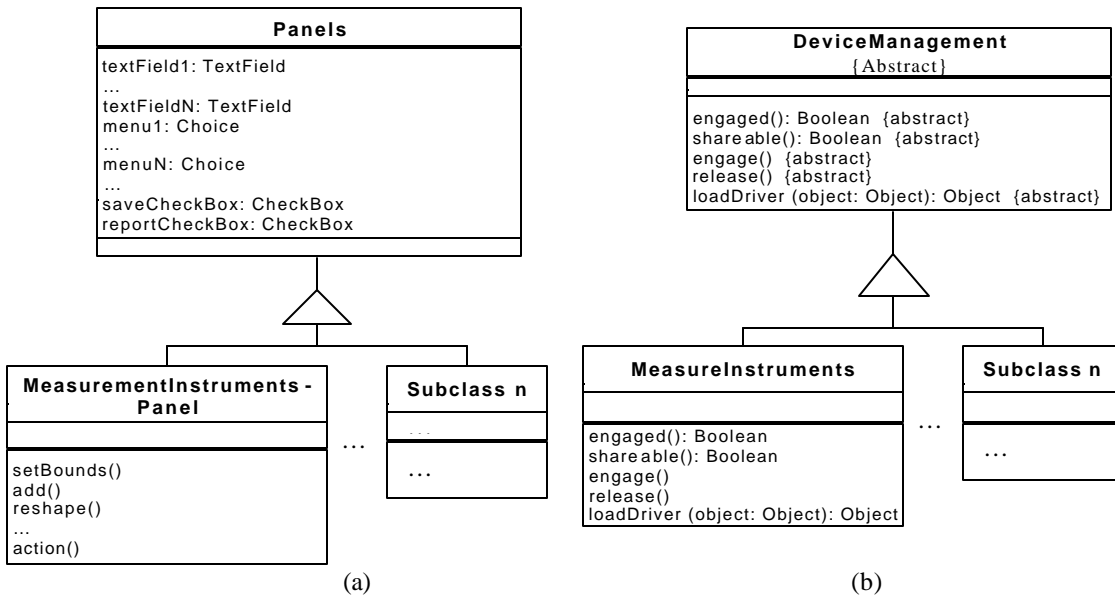


Fig. 3. UML class diagrams of *Panels* (a), *DeviceManagement* (b) and their subclasses.

the DUC has to carry out (e.g., volt AC/DC, current AC/DC, resistance 2/4 wire, frequency), the range of values of the measurements, the number of points per range and the number of measurements that have to be carried out for each point. Then, the same native method analyze the results of the measurements, correct in real-time the possible found deviation by some commands of the calibrator and return the calibration report. This contain date, outputs of the calibrator, minimum and maximum measurement values permitted from the reading and range uncertainty of the DUC, measurements executed by the DUC, deviations of the measurements from the outputs of the calibrator and the calibration timing.

The routine that manage the calibration operations has been realized in C, rather than for example in LabView, to increase the performance of calibration operations and to allow a quick upgrade of the calibration system when new measurement instruments need to be calibrate.

Using the Forte for Java tool, the third unit of the upgrading code has been implemented to create a graphical user interface for the client-side. In particular, the virtual panel shown in Fig. 4 contain the report of a calibration procedure executed on the Hewlett Packard 3440A multimeter.

Form [CalibrationPanel]

Wait for report

Save report

Instrument: Hewlett Packard, 3440A

Kind of measurement: DC VOLTAGE Range: 10 VOLT

File name: Path: C:\CalReports

Points per range: 3 Measurements per point: 2

Report:

Mon Feb 18 2002 14:33:40  
 Calibrator: Fluke 5500A  
 Device under calibration: Hewlett Packard 3440A, Multimeter  
 Measurement kind: DC VOLTAGE  
 Range: 10 VOLT  
 Number of points per range: 3  
 Number of measurements per point: 2

CAL. OUTPUT	INF. UNCERTAINTY	DUC READINGS	SUP. UNCERTAINTY	DEVIATION (ppm)	DEVIATION (%)	PASS/FAIL
0.00000	-0.00040	0.00002	0.00040	2.00000	X	PASS
5.00000	4.99985	4.99985	5.00015	15.00000	0.007564	PASS
10.00000	9.999810	9.999938	10.000190	61.900000	0.000619	PASS
0.00000	-0.00040	0.00003	0.00040	3.00000	X	PASS
5.00000	4.99985	4.99989	5.00011	11.00000	0.000228	PASS
10.00000	9.999810	9.999941	10.000190	58.700000	0.000587	PASS

The calibration procedure has been carried out in 24 seconds.

OK Cancel

Fig. 4. Client-side panel for the remote management of calibration operations.

## CONCLUSIONS

In this paper, an abstract client-server architecture has been described that controls instrumentation over the Internet. This architecture exploits the flexibility, the portability and the network-oriented features of the Java language, thus avoiding the use of proprietary software tools. Moreover, it has been conceived to allow an easy upgrade of the system when new hardware resources are connected to the server computer. This results from the high level of abstraction characterizing both client- and server-side applications. In fact, while the low-level control of devices is performed by

routines written in C, the use of abstract classes and the dynamic loading of native methods allow the client to communicate with every instrument, regardless of its specific properties. This approach to the remote management of instrumentation is further improved by the multithreading mechanism, allowing more than one user to take simultaneous measurements independently.

Exploiting the extensibility features of the system, a dedicated application based on the ACSA architecture has been developed to carry out calibration procedures remotely. In particular, an experimentation of this application has been dedicated to the calibration of some measurement instruments located in the laboratories at University of Perugia and connected to the server of the system by an IEEE 488 bus controller.

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