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13. ABSTRACT (Maximum 200 words)

Report developed under SBIR contract for Topic A98-155. It summarizes investigation of the state of the Automatic Test System (ATS) industry and approaches to reduce costs of control software, especially test program sets (TPS) and an investigation to foster an environment for the interchange of instruments without adversely impacting the TPSs. The concept of using generic instrument class (GIC) drivers was explored, including the process for developing and attaining industry concensus for using voluntary GIC specifications. Issues of scope and utility, generality, consistency, and inclusion of special features were explored. Technical solutions and the benefits of using component object model (COM) objects were investigated. Interchangeability of digital multimeters using GIC drivers was demonstrated to not impact the TPS.

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Harmonizing Automatic Test System Assets, Drivers, and Control Methodologies

SBIR A98-155 Phase I Final Report

prepared by
Neoteric Technologies, Inc.
P.O. Box 4709
Huntsville, AL 35815

prepared under
Contract # DAAH01-99-C-R021

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FAX (256) 704-5156
VOICE (256) 704-5154
neotek@ro.com

FINAL REPORT

J. W. Neiers

18 JUL 1999

The advent of the programmable computer created a continuing cultural and commercial dynamic of applying computer systems to an increasing number of tasks which increases the demand for computer components, enables economy of scale which reduces costs and further enhances the cost benefits equation for more applications. We are presently in an environment wherein it is economical to have excess functional capability to enable the broadest possible scope of applications in order to amortize development costs over the greatest number of units. This is especially true when considering the allocation of functions between hardware, software, or micro-code. Very large volume of demand fosters the production of small, capable, inexpensive hardware devices. The environment in which this process thrives is one in which multiple vendors can produce interoperable components, each according to its own special technologies and production expertise. Standardized interfaces and agreed upon functionality has been an underlying enabling factor for this environment.

The military recognized the benefits of using products from this environment, designated as commercial-off-the-shelf (COTS) devices. What is also now realized is that COTS devices change rapidly (that dynamic of applications functionality growth). Consequently, a critical element in reducing total ownership cost for any system that requires separate investment in components of that system, such as applications software, is that the impact of changing components does not adversely affect overall system performance. This is of particular concern for applications to automating testing of sophisticated electronic devices in military systems.

Such applications are a subset of Automatic Test Systems (ATS). In this domain, the devices being tested often have operational lifetimes measured in the decades. The application software that controls the testing is part of a Test Program Set (TPS) that typically represents a developmental investment of tens and even hundreds of thousands of dollars. Devices comprising the platform of the ATS, including instruments, are often replaceable for a few hundred or a few thousand dollars at most. The capability of replacement devices such as COTS instruments can be improved with components costing a few dollars or sometimes, even pennies. As new devices to be tested require new test devices, the capability to test legacy devices and the utility of the TPS for those legacy devices must be retained.

This issue has been around since ATSs were introduced into the military support community to reduce the total ownership cost of the primary weapon system. Throughout the 1970s into the '80s the military stressed standard architecture and standardized components in an attempt to address this issue. Commercial applications have currently outrun military applications so the military has effectively abandoned the concept of standardized ATS architecture in favor of COTS. Nevertheless, many of the interface standards in the COTS test community had their origin with the military standards. At the same time, the ATS community is sharing many common issues with other applications of computers. The computer industry, the software industry, and now the Internet community with its facilitation of distributed cooperative processes, have all been addressing methodologies to reduce the total ownership cost through greater interoperability of heterogeneous components, reusability of software, and platform independence.

It is in this environment that a focus on instrument drivers has a particularly attractive potential for reducing the total ownership cost of ATS by reducing the need to rework legacy TPSs when instruments are replaced. It is a major premise that careful attention to the design and standardization of instrument drivers can greatly increase interchangeability of instruments without affecting the application software. Instrument drivers is also an area of technology that is unlikely to be a focus of other software and computer disciplines. In the context of this focus on instrument drivers, the term instrument includes such ATS devices as stimuli and switches in addition to conventional instruments.

The context of an ATS instrument and its drivers is illustrated in Figure-1.

To maintain the focus on the instrument driver, it is imperative to describe the model of the ATS with each of the components necessarily not tightly coupled to the application software. Unfortunately, this isolation has not always been adhered to either because of attempts to speed performance by by-passing in place system features, lack of developer discipline, or lack of adequate system capability. However, with currently available technology, a generic model as illustrated in Figure-1 can be maintained with the resulting benefits of interchangeability of instruments and drivers without impact on the application program.

This instrument and driver interchangeability is premised on only a few simple constraints. One - The application program only communicates with the instrument through the instrument driver. This implies that the application software is unaware of the I/0 or the interface to the instrument. Thus, any change in the choice of instrument interface will not be visible to the application program. Two - that there is a driver uniquely tailored to each instrument that adheres to certain standardized Application Program Interface (API) for that class of instruments. Thus, any instrument within that class will present an identical interface to the application software.

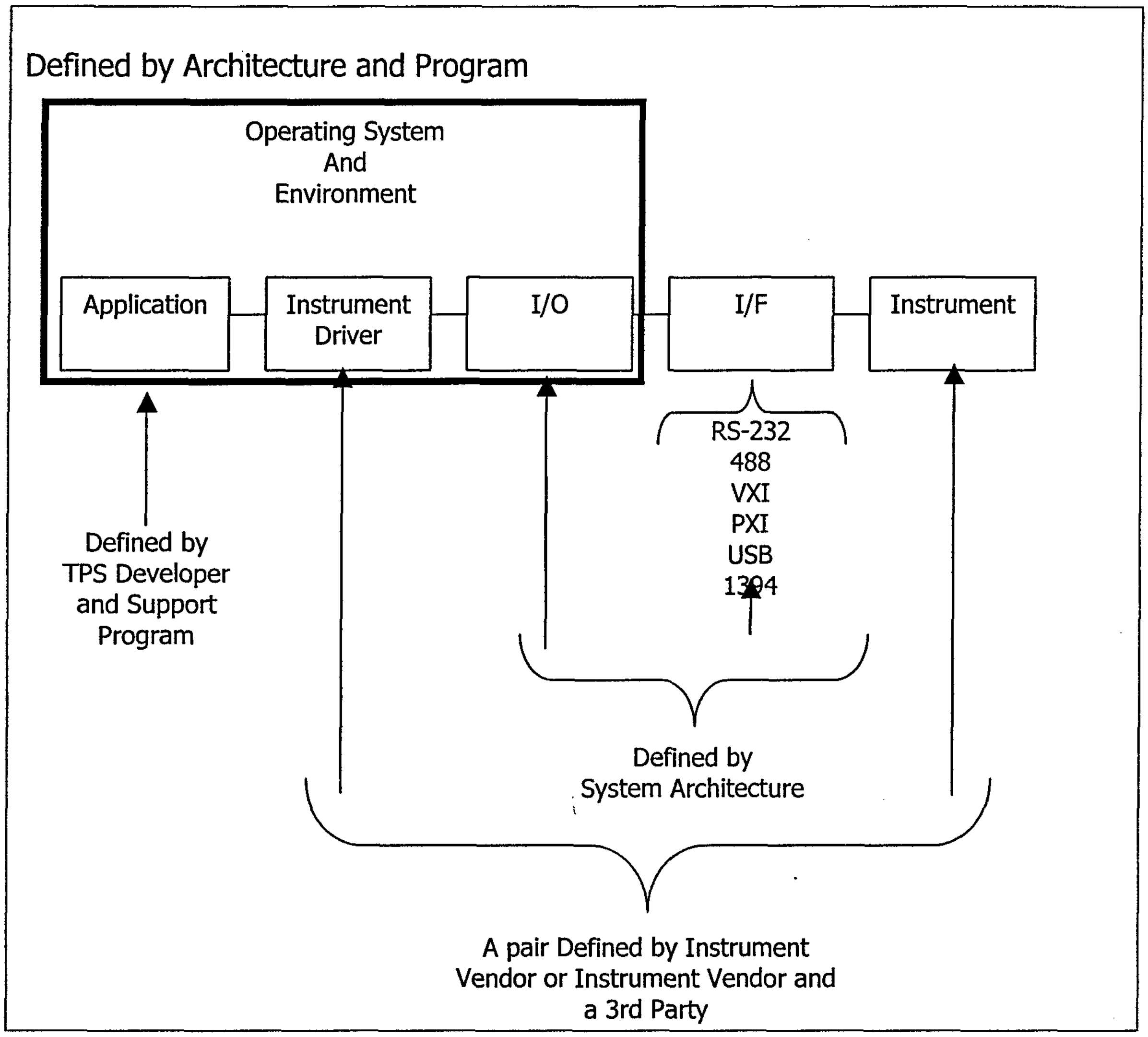

FIGURE-1
The Role of an Instrument Driver in an ATS

In the extreme, this API will be invariant over any instrument interface. This is especially relevant, as new and more flexible, higher performing interfaces are becoming more prevalent. Legacy instruments have RS-232, IEEE-488, or VMEbus eXtension for Instrumentation (VXI) interfaces. Most new instruments still have the 488 and many are VXI devices. A few are just now coming as PCIbus eXtension for Instrumentation (PXI) as that interface is getting better defined. Future devices will likely have a USB or an IEEE-1394 or its equivalert. Thus, instrument interchangeability must include the ability to use a different interface to the computer systems. There is a school of thought that believes future computer systems will have only two interfaces, USB and something comparable to 1394.

The concept of "instrument driver" necessarily is constrained in this model. Generally, every device has some executable software that controls it. Traditionally, for instruments this was a combination of the application program and whatever utilities were provided by the operating system or the specific test system environment, which was frequently called the "test executive", to properly handle details of the I/0 and specific interface bus transfers such as the 488 and standardized 488 instrument commands. It is precisely that integrated combination of allocation of functional responsibility that the "instrument driver" of this model avoids. The instrument driver presents a standardized API to the application. The instrument driver provides for the communication with the I/0 through the use of operating system and environment features that are established when the driver is installed.

Because all instruments do not have identical functionality or capability, it is impossible to create a single programming interface that works with all of them. Like instruments can be classified into common classes with similar properties. This will result in a taxonomy of classes. Within this taxonomy, many classes will share similar functional properties and will have the same programming interface. These various classes, arranged in an hierarchical taxonomy of shared properties, are called "generic instrument classes" (GIC). Within a class, there are certain functional properties that every instrument driver/ instrument must have. These functions are the core functions of the class. To accommodate other instruments with similar functions but additional capabilities, there are "extension " functions.

Because there are literally thousands of different instruments, it is a non trivial task to first classify, then specify, then implement, and finally to verify conformance of instrument drivers to the GIC specifications. Fortunately, this concept has been embraced by different groups of the instrument manufacturers, system integration, and user communities. Two groups of particular note are the VXIplug&play (VXIPnP) System Alliance and the Interchangeable Virtual Instruments (IVI) Foundation.

As the name implies, the VXIPnP Systems Alliance is concerned only with instruments that are VXI plug and play compatible. However, much of the work of this group in establishing frameworks, instrument driver models, distribution and installation requirements, specification development, and attention to common issues is applicable. Of particular import is the Virtual Instrument Software Architecture (VISA) I/0 driver architecture that provides a unified foundation for all existing points of view with platform independence and backward compatibility.

The other group that is aggressively addressing issues of GIC instrument drivers is the IVI Foundation. This is a recently organized consortium of companies chartered with defining software standards for instrument interchangeability. It consists of end-user test engineers and system integrators. This group is intentionally building on experience with the general-purpose interface bus (488) and VXI systems. The group is currently identifying instrument classes based on the most common functionality and configurations available in present day (1999) instruments.

1 Work Summary

As expected when the project was first planned, considerable activity toward similar ends is on going in the automated test community. The stated objectives and planned tasks stressed the early assessment of such activity for suitability as effort to apply and build upon for the development of GIC instrument driver standards. The plan also requires the early selection of a suitable standards setting venue and establishing a working position within that venue.

In Phase I, we set out to determine the feasibility of using GIC drivers to enable the easy interchange of functionally similar instruments without having an adverse impact on the TPS. This is one of many issues impacting the reuse of software. We recognized the need to investigate surrounding issues in context of the total control environment to avoid situations wherein one fixes a problem simultaneous and at odds with a similar 'fix' in another segment of the control path. We also recognized the need for assessing both technical feasibility and the acceptance of the marketplace or industry to any fixes requiring adherence to standards.

We determined that the concept of GIC drivers is both technically feasible and acceptable by a wide variety of stakeholders. We also determined that there is a definite convergence of technical solutions to software reuse and approaches to reduce ownership cost of systems with digital data transport or manipulation functions. This convergence includes the partitioning and definition of interface standards, cooperation among standards setting bodies, support by industry stakeholders for these interface standards, and a freeflow of cross industry segment technologies. The ATS community is not an isolated industry segment. The same techniques applicable to reduced ownership costs for the computer industry, the information technology industry, the software development industry, and the telecommunication industry are applicable within the ATS community. Devices and products are targeted to serve the broader markets that embrace several industry segments. The ATS, the automated calibration, and the automated data acquisition segments need not solve all of the associated problems by themselves. Reliance on the broader computer related industries makes good business sense.

The Department of Defense (DoD) sponsored ATS Research and development Integrated products team (ARI) working group came to a similar conclusion when they identified certain critical interfaces (CI) for reducing the cost of ownership for ATS and for fostering TPS reuse. One such CI is the instrument driver and the GIC concept. Other industry groups, particularly the VXIPnP Systems Alliance IVI Foundation also focussed on instrument drivers. Because of the work of these industry consortia, the ARI took a hands-off approach to GIC specifications, anticipating progress by the industry volunteers. In fact, the IVI Foundation has made great progress in developing appropriate GIC specifications.

Working within the IVI Foundation, we quickly concluded that the work of this organization provides an impressive base for the purpose of our research and we should build upon it for Phase II. Working within this organization also provided us with direct contact with all the major stakeholders in the success of the GIC concept -- end users, system integrators, instrument manufacturers, and tool and development environment suppliers. These stakeholders are anxious for the concept to succeed and are supportive of our efforts at advancing some critical areas that are not feasible with the current structure and interests of the volunteer organization members. **Demonstration of interchangeability of similar instruments and measures of the benefits of using GIC drivers is essential for the widespread adoption of the concept. There is also a great deal of work remaining to establish the IVI standards as functioning open documents to which anyone can develop a compliant driver with an assurance of an acceptable degree of interchangeability.**

We accomplished all of the objectives during Phase I. We followed the plan of leveraging existing work as it was appropriate, and influencing it in accordance with our analysis, for maximum benefit to this project goals.

2 Project Objectives

The overall objective of the project is to address total ownership costs of ATS, especially concentrating on reducing impact on legacy TPSs when instruments are interchanged. The subsequent objectives support this overall objective.

2.1 Objective 1: Produce a catalog of relevant standard activities

Task 1: Survey and Catalog Standardization Effort
Accomplishments: Investigated standards setting bodies and their products with relevance to ATS.

Compiled summary of activities and popular buses and protocols both found in legacy systems and likely to be used in future systems.

Catalogued information on over 250 terms, standards, and organizations relevant to project.

2.2 Objective 2: Assess suitability of frameworks provided by VXIPnP Systems Alliance and other relevant organizations

Task 2: Investigate VXIPnP and other approaches
Accomplishments: Reviewed activity of VXIPnP Systems Alliance and IVI Foundation.

Had numerous discussions with IVI Foundation members.

Investigated Test and Diagnostics Consortium plans and directions.

2.3 Objective 3: Select a justified framework for establishing GIC

Task 2: Investigate VXIPnP and other approaches
Accomplishments: Assessed alternatives to GIC drivers such as the Measurement Subsystem Architecture (MSA), use of standardized expert TPS generators and assistants, and standard resources. Concluded GIC drivers approach is fundamentally most appropriate for goals of project.

Defined model of desired instrument driver/ instrument relationship with the overall ATS.

2.4 Objective 4: Meet the requirements, both coordination and document generation, of a specification for the GICs to be submitted to a standards body

Task 2: Investigate VXIPnP and other approaches
Task 4: Synthesize Specification to Advance GIC Interoperability
Accomplishment: Selected IVI Foundation as body for initial coordination.

Investigated suitability of GIC drivers and identified additionally needed interface modules.

Identified issues and potential technical impediments to fully realize benefits of concept.

2.5 Objective 5: Validate those efforts through analysis of a set of representative assets that include:

Digital Multi-Meters
Counter-Timers
Digitizers

Power Supplies

Task 3: Analyze Sample Instrument Set

Digital Multi-Meters
Counter-Timers
Digitizers
Power Supplies

Accomplishments: Reviewed VXI PnP documents and IVI Specifications. Specifications and procedures including organization, approval, frameworks, and specific classes. All are in various stages of development and internal approval, either within ad hoc working groups or by the voting membership of the organization. In addition to framework and generic specification components, twenty-five specific instrument classes have been identified to have specifications generated. Of these, specifications have been developed at least in draft form for only eight. However, these do include: Digital Multi-meter (IVIDmm, IVI-5), Counter-Timers (IVICtr, IVI-10), Digitizers (included in Oscilloscope IVIScope, IVI-4), and Power Supplies (IVIPower, IVI-7). By one measure, the availability of these specifications represents an initial goal for the project. However, there are many issues associated with completeness, inconsistencies, and needs to meet acceptance as a viable standard.

Summarized present status of IVI standards.

Assembled a broad set of data for digital multi-meters for in depth assessment of suitability of IVIDmm - IVI-5.

2.6 Objective 6: Develop suitable GICs that accommodate the representative assets within the selected framework

Task 4: Synthesize Specification to Advance GIC Interoperability
Accomplishment: Began developing a test of Multi-meter drivers for HP 3458A and Fluke 8840 by writing a driver for each in accordance with IVI-5 to perform only core functions.

Developed a prototype interface and demonstrated interchangeability of HP and Fluke multi-meters using IVI GIC drivers for a limited subset of functions.

2.7 Objective 7: Develop methodologies for classifying generic instruments

Task 4: Synthesize Specification to Advance GIC Interoperability
Accomplishments: Working with IVI members on ad hoc working groups to address: Interchangeability checking, principles for class definition, and value of specifying classes in a language independent format such as Interface Definition Language (IDL).

Researched application of emerging artificial intelligence technology for automatically extracting inferred knowledge. Technology is Latent Semantic Analysis (LSA) and appears to have merit. Assessed approach to apply it.

Determined there are precursor issues that must be resolved first using more conventional approaches. LSA is still expected to have long term benefits.

Identified issues of generality, truthfullness versus consistency, taxonomy complexity, and naming conventions.

Identified generalized implementation issues with namespaces.

Assessed benefit of COM interface to increase generality and utility while resolving namespace issues.

3 Work Performed

Working within that context, we made significant progress in assessing the current state of consensus of stakeholders in the GIC driver concept. We determined that the IVI Foundation is the standards body most suitable to work within toward bringing the GIC driver concept to fruition. We performed studies that focused on the following areas.

3.1 Industry Wide Standards and Interoperability Attempts

We assessed the various standards setting bodies for relevance and selected the IVI Foundation. Of the hundreds of organizations determining standards, over 50 are involved with standards that have a potential of direct impact on ATS and instrument interchangeability. Some such as: 1394 TA, PC/104 Consortium, PCI SIG, PCMCIA, PICMG, EIA, VESA, and VITA have an emphasis on form factor, mechanical dimensions, and bus protocol. For an identification of the acronyms of the standards setting organizations referenced herein, see Table 1. Others such as ANSI, ISO, ITU, and IEC are more formal bodies and are reachable only after standards have been accepted by industry and proven workable first as voluntary ad hoc standards. Others such as: the Active Group, COS, OMG, and the Open Group, while having a direct impact on software reuse and potentially GIC implementation, are not the proper venue for GIC standardization.

3.2 Existing Organizations and Relevant Legacy Work

Standards setting groups of particular import to this project are: IVI Foundation, VXIPnP Systems Alliance, ARI, ODAS, Test and Diagnostics Consortium, and certain working groups within the IEEE. Each of these appears to be maintaining liaison with each other so our work within the IVI Foundation seems to be well placed for the purpose of promoting open specifications. We studied the documents already available from the IVI Foundation within the context of other activities with common goals.

3.3 GIC Driver Feasibility

We assessed the feasibility of the GIC driver concept, compared it to alternate approaches, and described the results in a paper "Reducing Total Ownership Costs of a Test System with Standardized Device Drivers", March 19, 1999.

Table 1 Organizations Affecting Instrument Interchangeability

ACRONYM	ORGANIZATION NAME	PRINCIPAL AREAS OF INTEREST TO ATS
1394 TA	Firewire Trade Association	Defining high speed bus protocol
Active Group		Accelerating ActiveX interoperability as an open standard compatible with the Open Software Foundation's Distributed Computing Environment
ANSI	American National Standards Institute	Primary US standards coordination body and US member of ISO and IEC
ARI	Automatic Test Systems Resources Interface	DoD sponsored group addressing specific issues of TPS portability, reusability, instrument interchangeability, and cost of ownership of ATS. Defined critical interfaces, including GIC
COS	Corporation for Open Systems	Offer architectural guidance and open standards for interoperable computer and communications equipment and services
EIA	Electronic Industries Association	Signal and communications interface standards such as RS-232-C and other serial buses and connectors
IEC	International Electro-technical Commission	Test procedures, interfaces, definitions, networks, and all related electrical and communications elements
IEEE WG	Institute of Electrical and Electronic Engineers Working Groups	Test and measurements buses, protocols, languages, resources, and ATS related standards
ISO	International Organization for Standardization	World wide standards, including measurement, data encoding, signal processing, and all related elements
ITU	International Telecommunications Union	Telecommunications protocols, regulations, frequency allocations. Formerly CCITT
IVI Foundation	Interchangeable Virtual Instruments Foundation	Generic Instrument Class drivers to promote instrument interchangeability
ODAS	Open Data Acquisition Systems	A consortium of PC plug-in data acquisition card vendors defining drivers for Common Object Model (COM) standard interface to assure interchangeability and interoperability
OMG	Object Management Group	Object oriented software development and management for interoperability, portability, and reuse
Open Group		Global open information infrastructure for interoperable, portable, and reusable software and data
PC/104 C	Personal Computer /104 Consortium	Specifications for embedded PC applications and devices

ACRONYM	ORGANIZATION NAME	PRINCIPAL AREAS OF INTEREST TO ATS
PCI SIG	Peripheral Components Interconnect (PCI) Special Interest Group	Specifications for small PCI and embedded devices
PCMCIA	Personal Computer Memory Card International Association	Standards for PC Card devices
PICMG	PCI Industrial Computer Manufacturers Group	Specifications for backplane electrical, mechanical, and signal compatibility
T&DC	Test and Diagnostics Consortium	Improved interoperability between test, built-in test, diagnostics, and maintenance for commercial systems
VESA	Video Electronics Standards Association	Interoperable displays and their interfaces
VITA	VMEbus Industry Trade Association	Standards for VME devices
VXI PnP SA	VMEbus eXtension for Instrumentation (VXI) Plug & Play Systems Alliance	Plug in interoperability of VXI devices

3.4 Status of IVI Foundation Standards

A fourth study performed during this period was an assessment of the status of the IVI Foundation documents and an identification of relevant issues. The status progresses from "proposed" through "draft" to "accepted". When proposed, those deemed most urgent are assigned to a working group for development. Likewise, as issues are uncovered, ad hoc working groups will study them and make recommendations. Once a specification is assigned to a working group, the group chair will produce a draft. It will then move through discussion and review with eventual acceptance by the entire voting membership of the foundation. At that point, it will be published for trial use with expectations of revisions and eventual forwarding to a more formal standards setting body. The IVI Foundation has the following documents in some degree of development. The status of each of the IVI documents is shown in Table 2.

In addition to those documents listed in the table, the following instruments have been proposed for GIC specifications: DWG/Bus Emulator, Network Analyzer, Serial Word Generator, 1553 Bus Emulator, Precision DAQ, Set Point Controller, Noise Figure Meter, Logic Analyzer, Synchro/Resolver, Voltage Comparator, Audio Analyzer, Simple Analog I/O, RF Signal Generator, Serial Bus, Time Stamp, and Static Digital I/O.

Table 2 -- Status of IVI Foundations Specifications

ID	Title	Date	Rev	Status	Instrument
IVI-1	Charter Document	Aug.98	1.0	Accepted w/ modification	NA
IVI-2	Operating Procedures	Jul.98	0.3	In Review	NA
IVI-3	Ivi Class Specification			In Review	NA
IVI-3.1	Ivi Architecture Overview Specification	Jan.98	0.1	In Review	
IVI-3.2	Ivi Inherent Capabilities Specification	Jan.98	0.2	In Review	
IVI-4	IviScope Class Specification	Aug.98	1.0	Accepted	Oscilloscope
IVI-5	IviDmm Class Specification	Aug.98	1.0	Accepted	Digital Multi-meter
IVI-6	IviFgen Class Specification	Aug.98	1.0	In Review	Function Generator
IVI-7	IviPower Class Specification	Aug.98	1.0	Accepted	Power Supply
IVI-8	IviSwitch Class Specification	Aug.98	1.1	Accepted	Switches
IVI-x.x	Ivi Digital Class			In Review	Digital
IVI-10	IviCtr Class Specification	Jan.99	0.3	DRAFT	Counter
IVI-11	IviSpcAN Class Specification	Jan.99	0.4	In Review	Spectrum Analyzer
IVI-12	IviPwMtr Class Specification	Jan.98	0.4	In Review	Power Meter

From the viewpoint of this project, we assessed the following areas as requiring refinement:

1) The details within the specifications are insufficient for unambiguous implementations.

2) There is a need for more complete definition of the higher level objects in the class structure. These are intended to be addressed by the IVI-3.1 and IVI-3.2 specifications, which are both in very early stages of development.

3) There is a need for a methodology to verify conformance and to test interchangeability of driver implementations.

4) There is a need for tools to identify class membership and even potentially the need for either a methodology or a specification for defining class membership. This implies a need for a rigorous taxonomy of GIC objects.

Discussions with Foundation members confirmed that some empirical demonstration of interchangeability and some comparison of drivers developed in accordance with the IVI specifications against other drivers would be extremely beneficial toward helping the GIC driver concept mature. There needs to be a much more specific definition of the software architecture into which the specific class specifications fit. This may require major revisions to existing 3.x documents or additional ones. A particularly important segment that must be resolved is how to specify required functions that are now tacitly performed by proprietary software.

Present implementations of IVI GIC Drivers are heavily dependant upon the proprietary National Instrument's (NI) LabVIEW or LabWindows/CVI Application Development Environment (ADE). This environment includes a library of useful reusable code segment and help in the form of a wizard to walk a developer through the use of templates to produce instrument drivers efficiently and uniformly. This package includes an "IVI Engine" that provides some degree of compliance checking. The degree to which this library and tools will become available through a "constrained public domain" grant by NI to the IVI Foundation is still under discussion. Theoretically, one is not constrained to use the proprietary NI tools, and with some development, the work of the IVI Foundation should be beneficial to developers using other ADEs such as Hewlett-Packard's (HP) VEE, TYX's PAWS, Visual BASIC, or C++. This is an area of the 3.x specifications in much need of work. Discussions with both NI and HP have led us to identify the importance of providing some statistically significant demonstration of interchangeability and measures of resulting work both with and without the use of IVI compliant GIC drivers. Our lessons learned and efforts directed toward these specifications will significantly advance the "methodology" for GIC driver development to achieve instrument interchangeability. An especially productive effort would be the demonstration and development of appropriate documents for COM interfaced drivers. This would likely require an additional 3.* specification. The resulting metrics and capture of methodology will be extremely important to the widespread acceptance of the GIC driver concept.

Once GIC driver specifications are developed for the more prevalent instruments such as Digital Multi-Meters, Oscilloscopes, Function Generators, Power Supplies, and Switches, the tasks become increasingly difficult. It is easy to have a proliferation of generic classes, thus negating the benefits for interchangeability. Likewise, it is difficult to properly categorize many instruments. The problem is exacerbated by different usage for identical terms by different manufacturers. One technique we discovered is the use of Latent Semantic Analysis (LSA) as a tool to aid in classifying an instrument function and in verifying compliance. This technique could help resolve different usage in technical manuals from the usage of identical words in the IVI specifications.

3.5 Latent Semantic Analysis

The technique of LSA may be quite suitable to addressing the issues of class membership, specification development, consistency checking, driver writing, and conformance checking. We briefly investigated this technology during the Phase I effort.

LSA is a mathematical/statistical technique to capture essential relationships between text documents and word meaning, or semantics. Statistical computations are applied to large bodies of text to determine and represent words of similar meaning in context, even though the same word may not even appear in two documents being compared. For instance, the word 'period' may be equated to 'time interval' based solely on similar contextual usage. If manufacturers' of different types of instruments used 'period' with different underlying definitions, that also could be detected.

The underlying theory of LSA is that any usage of a word in context is latently associated with a similarity of meaning of words and sets of words in relation to each other, along with mutual constraints as to what is meant and what is not meant. Since LSA originated within the cognitive science community and artificial intelligence researchers' attempt to model human language learning, some of the description can be rather esoteric. The fact is it has been demonstrated as effective. Given a college freshman psychology text-book, the LSA could correctly answer the multiple-choice questions to pass the course. Scores have been shown to overlap human performance in several areas such as standard vocabulary, subject matter tests, sorting, and category judgement.

The process is totally unsupervised, meaning that human intervention or training of any classifier is not required. It is not a traditional natural language process in that there is no human constructed semantic knowledge base required. There is no semantic network, grammar, or syntactic parser involved. Rather, only the statistical pattern of the bits representative of words (you pick the language), glyphs, or other picture characters is processed. In a practical application for GIC driver development, the data would be the ASCI representation of English text such as is found in the IVI Specifications and instrument manufacturers' operating manuals and other descriptive documents.

To envision the concept, consider a simple paragraph of *n* sentences. Each sentence is a concept and is represented as a column in a matrix. Each of the unique words is a row in a matrix. Each cell in the resulting *mxn* matrix will be assigned a number for each occurrence of the word in the concept (sentence). Each cell, with the frequency of occurrence, is then weighted by a function that expresses the importance of a word in the context and the degree to which it carries information about the domain of interest. Words like 'a' and 'the' are essentially removed from the analysis.

Next, singular value decompositions (SVD) is applied to the matrix. This is a type of matrix mathematics called factor analysis. In SVD, a rectangular matrix is decomposed into the product of three other matrices. One component matrix describes the original row entities as vectors of derived orthogonal factor values. Another component matrix similarly describes the original columns. The third component is a diagonal matrix containing scaling values such that when the three components are matrix-multiplied, the original matrix is reconstructed. The coefficients at the large dimensions of the diagonal matrix are of ever diminishing importance and can to be truncated, effectively compressing the resulting matrix dimension, with little loss of information.

In practice, contextual meanings of words can be determined by statistically analyzing large bodies of textual information such as encyclopedia, or for the GIC driver, Autotestcon and ATE&C conference proceedings and various technical journals. The resulting vectors are millions of elements long. Application of SVD can reduce the matrix dimensionality to a practical workable size. Research in LSA has determined that the greatest accuracy of semantic correlation occurs when the resulting matrices are on the order of 200 to 500.

LSA should be considered as a potentially powerful adjunct tool for improving the efficiency of determining instrument class membership and for validating resultant class drivers. However, its suitability is tempered by the newness of the technique and the fact that there is much room for first making progress in the development and acceptance of GIC instrument drivers using conventional techniques.

3.6 COM Objects

Component Object Models (COM) objects, are reusable binary software elements or objects. COM is a standard that enables these objects to communicate without requiring recompilation and linking of the entire system every time one object is changed. The importance of this is achieving awareness within the information technology community and will be even more relevant for the ATS community as a way to alleviate identified problems with GIC instrument drivers.

A COM object is language independent. It can be generated using a language of choice. It will conform to certain interface communication standards that enable any program to invoke the functions of the object. This sounds almost like magic and too good to be true. Yet, through an established standard for generating a globally unique identifier (GUID), the use of a registry, and standards for communicating the fundamental parametric requirements, COM objects can be reused within or outside the calling process and across platforms without regard to the physical location of the various software elements, the computers, or the environments.

This is a powerful concept that has a great potential for the GIC driver concept. It avoids the unmanageable growth of unique names encountered with the management of GIC source code. The TPS can communicate with the driver

API without requiring the overhead of mapping the different functions' names to an established neutral set. The present IVI standards begin all names with the instrument manufacturer's name so the same function must have a different name for each instrument, thus guaranteeing innate incompatibility. This approach is practical from a configuration standpoint but presents a problem for easy interchangeability without impact on the controlling software. The use of COM objects avoids this problem.

Of even greater significance is the potential for decomposing intricate functions into primitives or atomic elements. Some complex instruments such as a calibrator or the various digital bus emulators could be synthesized by the easy integration of atomic COM objects.

3.7 Interchangeability

Interchangeability of assets is the ability to replace a given asset with an alternative asset of sufficient capability but of different design or manufacture. One hundred percent interchangeability, meaning all functionality all of the time for every instrument in a class is unrealistic and unachievable with finite resources. However, even a substantial degree of interchangeability, such as 80 percent of the functions 80 percent of the time is a worth while goal. Another measure is that on average, the amount of rework required when interchanging instruments is reduced to a small part, such as 20 percent, of that traditionally required.

3.8 Interoperability

Interoperability of applications is the ability to run a given application program or TPS on multiple physical configurations of test equipment.

3.9 Other Issues

Other issues were deemed important to the overall success of the GIC driver concept, but as less critical for immediate implementation. Initial examples included :1) the relevancy of the Measurement Subsystem Architecture (MSA) or its alternate name Measurement Stimulus Subsystem (MSS), 2) the need for language independence of the specification, and 3) Class Taxonomy and treatment of complex hybrid devices.

4 Experimental Work/Test Procedures

As a means to verify the basic concept of enabling instrument interchangeability using GIC drivers that conform to the IVI Foundation GIC Specifications, we experimented with some of the products produced by the IVI Foundation members. The GIC specification IVI-5, IviDmm Class Specification was sufficiently developed that conforming drivers could be written. National Instruments (NI) had written and made available, conforming drivers for both the HP3458a and the Fluke8840a multi-meters. These were written to work with the NI proprietary IVI Engine, although the intent is for the IVI Foundation with the help of NI to provide a non proprietary less capable version. Only a small part of the functionality is required for using the IVI compliant GIC drivers. We wrote alternative software to negate the need to use the NI IVI Engine and that enabled a visual interface to control and simulate the calls from a TPS to the multi-meter. We successfully demonstrated interchangeability of different manufacturers' instruments using the GIC driver concept.

5 Design

Not applicable

6 Test Equipment

Hewlett-Packard 3458a digital multimeter
Fluke 8840a digital multimeter
Hewlett-Packard E363a power supply
Fluke 5700a Calibrator

7 Test Performed

Demonstration of similar voltage, current, and resistance measurements from the same interface using calls to each of the Hewlett-Packard and Fluke digital multi-meters.

8 Failures

None

9 Difficulties/Problems

No unforeseen problems have been encountered.

10 Issues

There are several issues concerning the best technical approach to maximize instrument interchangeability while minimizing adverse impact on control software. These issues generally arise from the need for consensus among all stakeholders and the natural tendency for each to want to postpone any personal impact. Because of the breadth of participation in the IVI Foundation, cross membership in other organizations with related goals, and established liaison functions among standards setting organizations, we expect all these issues to be resolved in due time. However, this natural time constant may be unnecessarily long. A judicial application of resources to specific areas will accelerate benefits of reduced ownership costs. The following identification and discussion of some specific issues should offer some guidance as to what those areas are.

10.1 Buses

The ATS community has traditionally restricted itself to issues of the external I/O computer buses directly interfacing to instruments. These are usually limited to such serial buses as RS-232, RS-422 and 423, RS-485, the IEEE-488, and VXIbus. Interfaces to these buses are sufficiently isolated from the GIC drivers that they need not be a factor in the development of GIC driver specifications. However, with the increased distribution of computational resources in the prime systems and an increasing emphasis on built-in-test and diagnostics in the prime systems, consideration of other emerging buses is a must. Higher transfer rates using the cross bar switches and fabric concepts for VMEbus and PCIbus based chassis, miniaturized formats built around the PCIbus protocol, and fundamental changes in computer architecture with the universal serial bus (USB) and firewire (IEEE-1394), will drive the reallocation of functions in all computer controlled systems. This directional change will impact the utility of GIC drivers and their long term benefits. Proper consideration now will assure their beneficial position in the changing environment.

10.2 Names, Labels, and Hierarchies

This seemingly non-technical issue is at the heart of most of the discussions in arriving at consensus for specifications. As generality is stretched to increase the scope of a particular element, the greater are the incompatibilities that are identified. The dichotomy of preceding a function name with the unique instrument manufacturer's name was previously discussed. This aids configuration management of the documentation but hinders interchangeability.

Consistency across instruments is also at issue as analogous functions may take on entirely different meanings for different instruments. This is a consistency versus truthfulness notion. From a human standpoint, it is desirable that the structure of the APIs to each GIC driver be consistent, even to using identical names. Yet it is not desirable that a word like 'READ' means 'WRITE' when the instrument changes from a sensing and measurement device to a signal generation device.

The whole taxonomy of GICs soon becomes an issue once the simple multimeters, scopes, and power supplies are accommodated. Digital bus emulators and special purpose complex devices such as calibrators are difficult to treat as generic. Too fine a granularity and the set has a population of one. Too course a granularity and the useful functions are not accommodated. At immediate issue is whether to ignore those more complex devices or to address them with a more sophisticated technical arsenal such as through assemblages of COM objects.

10.3 Organizational Efforts

This is hardly a technical issue, but it is an issue impacting the speed of success for the GIC driver concept. The IVI Foundation is the single organization with the primary focus on promoting GIC drivers. The organization's effort has initially concentrated on developing specifications for the more commonly encountered devices as illustrated in Table 2. There have been a limited number of technical investigation tasks performed within the organization. The limitations of a volunteer organization necessarily limits the quantity of such tasks that can be accomplished.

There is still an open issue as to the long term operating functions such as education, promotional materials, and resource sharing. There are presently no provisions nor incentives to encourage members to develop drivers and to make them available to either the membership or the ATS community at large. Resolving such issues will impact the rate of acceptance of the GIC driver concept and the resulting payback.

10.4 COM

The adherence to and the requirements for COM standards is yet to be addressed. The present position of the IVI Foundation is to not prohibit the use of COM and appears to be one of favoring it. From a technical standpoint, COM will alleviate many of the anticipated problems. Full adoption of COM will possibly enhance acceptance of the GIC driver concept. However, near term ambivalence does not seem detrimental.

11 Results

The results of the Phase I effort far exceeded the objectives, primarily because of exogenous activities. Other end users and stakeholders in the ATS and TPS community perceived a similar need and cooperated in the IVI Foundation to advance the GIC driver concept. We were aware of this activity at the start of Phase I and extended our assessment of the state of the ATS industry to include a concentrated assessment and comparison of the IVI Foundation's scope, processes, products, and status.

As a result of this study, the following statements are justified:

1) This study resulted in a current assessment of the state of the ATS industry. This assessment is documented in the discussion of Section 3. The highlights are that there is a convergence of the ATS industry and the information technology community. The ATS community is realizing that adaptation and co-opting of the trends and technologies of the larger base is advantageous and the ATS focus is concentrated on specific data acquisition, test, and measurement issues.

2) Interchangeability and interoperability are deemed desirable by all stakeholders: end users, system integrators, and instrument suppliers. The concept of open interconnects is well accepted and the idea of retaining proprietary interfaces is no longer considered a viable strategy by most stakeholders. Realistic expectations are the norm for interchangeability and interoperability.

3) Cooperative endeavors are being pursued by a variety of organizations, each with awareness and intent to complement each other; each with areas of specialized interests. The IVI Foundation is the primary venue for GIC drivers. This organization has the needed representation of end users and instrument manufacturers; it has established processes and the beginning of GIC driver specifications; it is using applicable standards of the VXIPnP organization; it is cooperating with ODAS; and it has liaison with other interested organizations, such as the Test and Diagnostics Consortium, and standards setting bodies.

4) Consensus for specifications is essential. The process and participants of the IVI Foundation have demonstrated that consensus can be reached. It is also

a lengthy and incremental process. As progress is made on one issue, additional issues are uncovered and worked, often with beneficial guidance for additional technical investigations.

5) A series of current issues were uncovered. These are discussed in Section 10.

6) While there is a consensus as to the desirability of GIC drivers, there is a need for some quantified demonstration of economic benefits. The perception of intangible benefits is there. As yet, there is no hard data.

7) Feasibility for limited scope and devices was demonstrated. The demonstration helped uncover and confirm potential problem areas as conditions expand. The need to handle namespace is a major concern.

8) The use of COM objects will alleviate many of the recently identified issues. However, there is a need for more detailed investigation and demonstration of the COM object approach. The COM approach has not been fully integrated into the GIC driver concept.

9) Continued progress in achieving benefits of GIC drivers will require significant support from major end users organizations. The inherent benefits to suppliers, instrument manufacturers, and even system integrators is much less than for end users. Consequently, their investments will be necessarily limited. Without a significant investment in support to an organization such as the IVI Foundation, progress will be slowed. National Instruments has invested significantly in getting the IVI Foundation going. It is questionable as to how long they will continue the current level of support without having a diminishing effect on the openness and independence from proprietary products.

12 Estimate of Technical Feasibility

We determined from our Phase I effort that the GIC driver concept is feasible. Because of the nature of this project, feasibility had to be assessed both for technical considerations and for acceptance by the necessary community. The two views are closely linked as technical approaches can alleviate impediments of individual stakeholders. Benefits increase with the breadth of devices spanned at the same time as there are increased possibilities of incompatibilities of competing approaches.

Modern software environments with widespread availability of tools to manage diverse software, information technology community wide development of interface standards and approaches to increase software reuse, and the willing formation of industry groups intent on fostering interchangeable and interoperable information technology components all lead to the conclusion that the GIC driver concept is feasible. Demonstrated progress in developing and achieving consensus on GIC driver specifications for a limited set of devices further supports this estimate. There has already been a significant investment by the ATS industry in the concept of GIC drivers. Support must continue to maintain the momentum and to achieve measurable economic returns in order that the effort can continue to achieve widespread implementation.

NEOTEK Neoteric Technologies, Inc.
3077 Leeman Ferry Road
P.O. Box 4709 Huntsville, Alabama 35815

October 20, 1999

Pat Mawby, DTIC-DCA
Defense Technology Information Center
8725 John J. Kingman Road
Suite 0944
Ft. Belvoir, VA 22060-6218

Subject: Final Report, SBIR Phase I A98-155

Reference: DAAH01-99-C-R021 - Harmonizing Automatic Test System Assets, Drivers, and Control Methodologies. My letter and submission of September 30, 1999.

Dear Pat Mawby,

Attached is a revised Form 298 for the subject document. The revision to permit unlimited distribution is in accordance with the wishes of Neoteric Technologies Inc. and is acceptable to the AMCOM Contracting Officer.

Sincerely,

James W. Neiers

James W. Neiers
Vice President, Neoteric Technologies, Inc.

attachment

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U.S. Army Aviation and Missile Command - DSN 788-9937
ATTN: AMSAM-TMD-EW
Redstone Arsenal, AL 35898-5000

23 NOV 1999

Per telecon w/Mike Locque, AMCOM, technical contact for above report, he agrees with Neoteric Technologies Inc, to change the distribution to unlimited.

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Anna Hunner

Phone ~~205~~ 256-650-4601 FAX ~~205~~ 256-650-4607