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PERSPECTIVES OF SOFTWARE FOR MEASUREMENT AUTOMATION

Pasquale Arpaia [1,2], *Ernesto De Matteis* [2,3], *Vitaliano Inglese* [2]

[1] University of Napoli Federico II, Naples, Italy
[2] European Organization for Nuclear Research(CERN), Geneva, Switzerland
[3] University of Sannio, Benevento, Italy

Abstract - The world of software for measurement and test applications is analyzed by considering the state of the art in research. Software tools and applications for instrumentation and measurement research are examined, by looking for main trends in the related scenario and a synthesis of the most promising advancements.

Keywords: application software, software systems, automatic programming, review

1. INTRODUCTION

In general, automatic test and measurement (or data acquisition) systems are used to assess experimentally parameter values of a process, a product, or an experiment. In particualr, monitoring systems are integrated in process/plant supervision and control, because the measured values are not used directly (i.e. as a part of the same system) to adjust automatically the process/plant under test [1].

At industrial level, the increasing automation in the production process amplifies more and more the needs for accurate measurement systems for quality control and, consequently, the need for developing the related software. At scientific level, analogously new experiments and machines (like particle accelerators, astro-telescopes, or space missions) require impressive performance to automatic measurement and systems, often well beyond the state-of-the-art limits [2].

The choice of the appropriate application software for an automatic measurement system is an important step for all the test operators. As a matter of fact, the software is the core of modern automatic measurement systems. For selecting a suitable development tool, main imperative is handling the scalability as the measurement systems matures and evolves, in order to avoid the code to be rewritten. But software developers face also the challenge of producing reliable and high-quality applications in a very-short time [1]. Moreover, another key need is the integration of different families of various measurement instruments, by minimizing configuration and measurement time. Finally, the software for measurement applications should be highly effective to exploit first the increased throughput of the new transducers and acquisition systems and, simultaneously, to keep flexibility, re-usability, maintainability, and portability in order to maximize its quality. In this paper, the research and development horizon of the software for measurement automation is reviewed in order to focus main motivations and needs in current innovation trends.

2. RESEARCH SOFTWARE STATE OF THE ART

The objective of this Section is to analyze the research and the development of software in measurement applications, such as for industry, science, and other fields. In scientific literature, the measurement-oriented software is integrated in automatic test or real-time monitoring systems. The software applied to measurement methods can be flexible with respect to the specific application field. A more useful strategy for classifying the research state of the art is to analyze the software applied to automatic measurements from a technical point of view. From this viewpoint, in research papers, three main classes can be identified (Fig. 1): *Hardware and Software Platforms*, *Specific and Custom Software*, and *Development Environments*. A platform includes a hardware architecture and a software framework combined to run application software. Specific or custom software (also known as bespoke software or tailor-made software) is expressly developed for specific instrumentation, devices, sensors networks or particular setup, applied and found in literature. Looking into the first two classes, a third class, tranversal both of them, is represented by *Real Time Systems*. Finally, the software can be classified (Fig. 1) according to the environment or language used for implementing the measurement system (Paradigm Programming, Domain Specific Langage, Visual Programming Language, and so on).

2.1. Hardware and Software Platforms

In literature, the research trends related to Hardware and Software Platforms point out different features, mainly hardware and /or software nature, or specific technical keywords, such as flexible, frameworks, distributed, and so on. Accordingly, the corresponding branch of the tree in Fig. 1 is divided in two main trend sets: *Flexible Measurement Systems* and *Distributed and Diagnostics Systems*.

Flexible Measurement Systems

In general, research trends on flexible measurement systems put main design focus on flexibility, modularity, generality, and hardware independence [3]. They represent software architectures meeting specifically these requirements by innovative solutions, and structures expressly conceived for implementing versatile

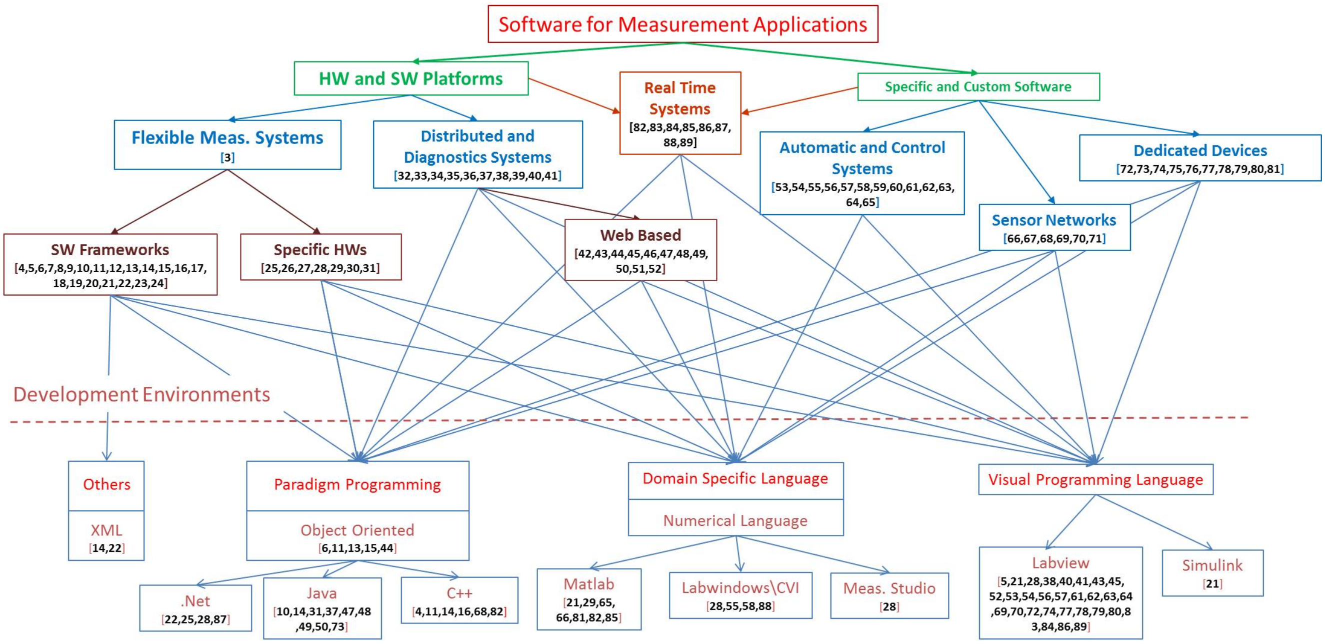

Fig. 1. State of art Research Tree: Software for Measurement Applications.

measurement systems. Typically, flexible measurement systems are based on software packages (monitoring with data acquisition, processing, transmission, and storing, as well as result analysis), with various possibility of communication. They are applied to different industrial operations, such as the protection of plants operation, system supervision, detection, and provision of measured values. In research trends about flexible systems, other two specific classes can be distinguished: *Software Frameworks* and *Specific Hardware* systems emphasizing software and hardware aspects, respectively.

Software Framework: All the innovative measurement systems exploiting a software framework privilege flexibility and integration. A framework allows software for measurement and test applications under highly and fast-varying requirements to be developed easily. The framework can be configured for satisfying a large set of measurement applications and operation users in a generic field for an industrial test division, a test laboratory, or a research center [4]. A software platform can be designed for particular hardware or functional requirements, but with the specific aim of providing the *development of new features* [5, 6]. Other types of frameworks are general tools for automatically *analyzing* the measurement data [7, 8, 9], or the *dependability* of measurements and algorithms on distributed systems [10]. The generic *object-oriented* based frameworks present the main advantages of object-oriented programming: encapsulation, inheritance, flexible-construction, and multi-task options. This allows both object-oriented databases to be created for measurement, and expert systems or test platforms to be built for processing measurement information [11, 12, 13, 14, 15]. A model-driven paradigm for defining measurement/test procedures, configuring instruments, and synchronizing tasks is applied to a flexible framework for maximizing the *software quality* [4, 16]. An increasing research trend is arisen aimed at conceiving measurement frameworks [17, 18] for general-purposes and rapid prototyping of frameworks for end-to-end sensing systems, in order to *monitor and diagnose* problems on a wide-area network [19]. In [20, 21], global framework for monitoring and control and optimization of power electronics systems are described. Component-based frameworks for data stream processing are presented for highly-distributed measurement systems [22, 23]. Other software development environment, framework-based, provide a *graphically programming* way to quickly build automatic test and measurement systems [24].

Specific Hardware: Sometimes, software packages are present in specific hardware-based measurement systems for keeping specifically the feature of flexibility. The class treats different measurement fields (*monitoring*), and aspects (*simulation, and design*). About *monitoring*, as an example, in [25], the data acquisition hardware platform of three-dimensional machining force measurement presents a flexible software package for on-line monitoring, analysis, and testing. Analogously, flexible monitoring and signal processing platforms with modular software were developed for biomedical application [26, 27] and vibration analysis [28]. Regarding *simulation and design* aspects, a flexible radar system simulator applied for tank level measurement emulates the effects of antenna designs, thus to accelerate the verification process [29]. In [30], the design of an experimental flexible energy measurement system, consisting of distributed sensor networks with versatile and agent-based communication software is treated. A structured graphical method applied to design and implementation of intelligent instruments is presented in [31], where the conceptualization of the system is put in a new graphical object oriented tool.

Distributed and Diagnostics Systems

In literature, a subgroup of research trends on flexible measurement systems is devoted to distributed and/or diagnostics-oriented measurement systems. Differently from a traditional centralized data acquisition, the approach is to distribute the devices around the specific application, in order to both interact locally in the test environment, and have a cheaper and less complex system. Research is devoted to integrated software platforms for test and diagnosis based on data services, packages, and definition of interfaces [32, 33, 34]. New software tools are applied to measure the temperature and humidity accurately with low cost [35, 36]. Particular attention is paid to the management software of the acquired data, in monitoring applications [33, 37], to automate the measurement tasks [38, 39]. The development of virtual instrumentation is presented in [40], applied to torsional vibration and phasor measurement, respectively. A platform for simulation and real-time autonomous guided vehicles navigation [41] employs software architecture and code to reduce development time necessary for debugging, optimizing control algorithms and identifying system.

Web-based: A further significant research trend is devoted to distributed measurement systems classified as web-based (Fig. 1), owing to their feature of remote control and monitoring by internet. In [42, 43, 44, 45, 46], *integrated laboratory* environments are aimed at providing remote access to heterogeneous equipment for a multiplicity of users. Web tools, based on *object-oriented* programming and client/server communications, have been developed for allowing remote configuration and flexible management of remote instruments [47, 48, 49]. In [50] and [51], *WWW-based* software environments are used for the design of panels of virtual measuring instruments, and for measurement data access, respectively. Integrated systems, again based on the web, are applied to remote monitoring and control of *industrial processes* [52].

2.2. Specific and Custom Software

In the state of the art of research, often software applied to measurement is difficult to find, and most of the times, it represents an accessory component of research proposal, usually hidden in the hardware description. From this point of view, another category of software application, Specific and Custom Software, is identified (Fig. 1). However, by analyzing the literature, different technical features of these specific and custom systems can be distinguished. The technical features are referred to the following particular application system: 1) *Automatic and Control Systems*, 2) *Sensor Networks*, and 3) *Dedicated Devices*. In the following, a general discussion of these software applications is presented.

Automatic and Control Systems

The nature of a control system of a process involves first a comparison between the current measurements and a reference value, and, then, in presence of differences, a suitable feedback response. The main feature of this kind of systems is the specific application to be controlled, and from this, the relative software is specific and customized to the control application. About energy control software, typical examples are virtual instruments developed for automatic measurement systems applied to power systems monitoring [53, 54], or to battery resistance measurement [55]. Moreover, a multifunction virtual instrument system for harmonic measurement of voltage and current signals is designed and implemented in [56]. In the transmission control field, an UHF radio-frequency identification tag test and measurement system based on virtual instrument programming is proposed in [57]. In a power flow controller of AC transmission system, a software development system for measurement and control field is employed for the system application [58]. For measurement and control on high-precision motion platforms [59, 60], software systems are implemented to controlling the main components of high-precision system. Based on the principle of virtual instrument, a measurement and control system for sling stretch test machine was constructed via the software platform [61], and for motion control of pipeline inspection robot [62]. For condition monitoring application, the design and development of the data-acquisition and storage parts of a measurement system include pc software implementation of virtual instruments [63, 64]. Finally, a graphical software tool with user interface was implemented to assist the selection of extrapolation methods for moving-boat ADCP streamflow measurements [65].

Sensor Networks

A sensor network is a network of spatially-distributed autonomous sensors for monitoring physical and chemical quantities. Differently from the *Distributed systems*, each node of the network carries out only sensing, acquisition and data transmission with centralized control and processing. Differently, sensor networks are still considered as distributed systems for the measurement, but with centralized control and processing. In other terms, each node of the network carries out only sensing, acquisition and data transmission. More modern networks are wireless and bidirectional, also to enable control systems, and are used in many industrial and consumer applications, such as health monitoring, industrial process, machine control, and so on [66]. For continuous monitoring with multi-sensor data acquisition GPS-based technology, the measurement techniques are based on general-purpose [67] and on embedded software [68]. In [69], a temperature measurement and control system for constant temperature reciprocator platelet preservation box is designed based on Fuzzy-PID control, and virtual instrument software. A Multipoint Wireless Measurement System is presented with multiple sensors transmission and virtual instrument interface for data processing [70]. A virtual instrumentation support system that permits to run several concurrent virtual instruments has been developed like a multi-tasking graphical environment [71].

Dedicated Devices

The class of software for dedicated devices includes all the packages designed and conceived for custom devices set apart for special applications. About the integration and control, for the on-line diagnosis of reactive plasmas, a flexible data acquisition and automatic control system based on virtual instrument programming [72] was designed to control and integrate all the stand-alone measurement instruments including a TOF spectrometer, a high-performance oscilloscope, a laser system, and a digital delay generator into a single personal computer-based control unit. In [73], for the Ionospheric Bubble Seeker, a new post processing technique based on the Java programming language was developed for all the operating systems and allowing also a remote control. Also integration-oriented are the virtual instruments presented in [74, 75], the former is an auto-measurement system of wave-plates phase retardation, and the former a software for tests of Large Binocular Telescope. About the flexibility aspect and/or the capability of making user friendly a particular hardware, typical example are related to a virtual instrument integrated with a power network analyzer [76] or the implementation of the measurement communication of a weather station [77]. Other dedicated devices are inserted in traditional measurement and monitoring systems, such as the system applied to leakage current of insulator using a virtual instrument for analyzing the data [78], and the grounding measurement system of substations adopting a virtual instrument to implement the small electric current method [79]. Finally, in [80, 81], custom software is implemented for measuring RF chip properties and for testing AD converters, respectively.

2.3. Real-Time Systems

In the state of the art of software applied to measurements, real-time systems represent a transversal feature. For this reason, this kind of software applications is positioned at the center of the classification tree (Fig. 1). The main feature of these systems is to guarantee response within strict time constraints useful for application purposes as *control* or *monitoring*. In [82], a *control* system, for verifying the film thickness in copper chemical mechanical planarization (CMP) offline modules), presents an in-situ module, developed in C++, for real-time measurements. A real-time system with bio-feedback devices for rehabilitative postural control [83] is implemented by a software framework. The control system of [84] measures the characterization of electron device degradation under nonlinear dynamic regime by real-time software. An experimental design and construction of a real-time system for measuring frames of water flow is pointed up in [85]. About *monitoring* applications, the paper [86] presents a sensor network for stem cell culture process. In [87], software developed in visual basic designs a real-time overload monitoring system for bridges and roads. An automatic system for avionics electro-mechanical actuators, based on multi-threading technique software (Labwindows/CVI) is presented in [88]. In [89], a dedicated automatic system for sieving chips evaluates the testing results in real-time.

2.4. Software Environments

In literature, different platforms or programming languages, used for developing the measurement applications, can be identified. First of all, the authors tried to identify the programming paradigms and languages adopted (see fig. 1). The software environments have been divided in four categories: Paradigm programming (Object-oriented), Domain specific language (Numerical language, such as Matlab, Labview/CVI, Meas. Studio), Visual programming language (Labview, Simulink), and others. In second analysis, main consideration regards the impossibility of founding a direct link between technical software features and the used software platform. However, two main trends can be identified: the former is related to the transversal use of user-friendly platforms, and the latter to the link between the nature of the measurement application and the choice of the implementation environment. In research project applications of large size [4] and particular typology [5], using object-oriented programming can result more suitable to satisfy measurement requirements, such as dynamic modeling, data fusion of instruments, and user-oriented approach. Conversely, for automatic control application or dedicated devices that provide stand-alone software implementation, a visual programming platform is preferred for aptitude and usability.

3. CONCLUSIONS

A review of measurement automation software was tackled in this paper. The main aim is to create a classification of software applied to measurement field, and secondly, to give a sound methodology to researchers for choosing measurement-oriented software. About the classification strategy, three main classes were identified: *Hardware and Software Platforms*, *Specific and Custom Software*, and *Development Environments*. The *software frameworks* allow the development of applications under highly and fast-varying requirements, and the decentralization of distributed systems is mainly given by *Web-based* system, owing to their feature of remote control and monitoring through internet. The class *specific and custom software* includes software, performing as an accessory component of a measurement research proposal, and usually hidden in the hardware. The class *specific and custom software* includes software, performing as an accessory component of a measurement research proposal, and difficult to be considered as a separate function because usually hidden in the hardware. About the *software environments*, the main remark is the absence of relationship between technical features and software platforms. A classification for programming paradigms and languages has been carried out (Fig. 1). Two main trends were identified: firstly, the transversal use of user-friendly platforms, especially for custom applications, and secondly, the link between measurement application nature and implementation environment choice. Owing to the complexity of this research and the quickness of software evolution, the authors apologize for the omissions surely present in this paper.

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