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INDUSTRY 4.0 LEGACY SYSTEMS INTEGRATION CASE STUDY

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Abstract:

This paper presents a methodology for modern systems integration of a legacy infrastructure. Commissioned in 1992 this infrastructure is used for large/industrial flow meter calibration and R&DI in Hydrology and Hydraulics. A solution for linking legacy devices and hardware in a new distributed system architecture, that foster future upgrades and modernization of the infrastructure, is proposed.

The presented case study aims to overcome, in the industry 4.0 era, the constrains and limitations of proprietary legacy field bus (Modbus Plus) and the monolithic SCADA legacy approach and to provide a modern system integration towards a distributed IIoT architecture.

Keywords: industry 4.0; legacy systems; SCADA; IIoT; system integration

1. INTRODUCTION

In the industry 4.0 era, the demand for modernization of laboratory testing and calibration infrastructures poses new challenges. The growing capabilities, along with the reduction of unit costs, of ubiquitous computing devices—such as Industrial Internet of Things (IIoT) devices, sensors networks, etc.—, are leading to an unprecedented ability of machines and devices to connect, communicate, and generate valuable heterogeneous big data sets. Thus, recently, intense efforts towards the digital transformation in metrology and especially in the Digital Calibration Certificates are being developed [10]. Yet, legacy systems—hardware, software and communication field protocols—are often found in current laboratory facilities. This leads to poor system integration and blocks laboratories from capitalizing on the advantages that digitalization creates.

In the last decade, microcomputers have become more powerful and affordable. Nowadays, a single board computer (e.g., Raspberry Pi) has several physical interfaces, and enough computing power to perform message broker [11] functions—thus enabling the linkage of the legacy systems with modern industry 4.0 systems. Combined with industry environment open-source software (e.g., OpenSCADA, Node-RED), this forges a path for state-of-the-art and cost-effective Supervisory Control and Data Acquisition (SCADA) systems implementations and enables the extension of the legacy industrial devices' life cycle.

A legacy system upgrade case study, at LNEC's laboratory infrastructure, is presented. The constraints experienced with legacy industrial devices and the strategies implemented to modernize this facility and enable future upgrades are also discussed.

List of acronyms:

DDE	Dynamic Data Exchange (in communications protocol)
HMI	Human Machine Interface
IIoT	Industrial Internet of Things
OS	Operating System (in computers)
PC	Personal Computer
PLC	Programable Logic Controller
SBC	Single Board Computer
SCADA	Supervisory Control and Data Acquisition
TCP/IP	Internet protocol suite
VB	Visual Basic

2. INFRASTRUCTURE AND SYSTEM DESCRIPTION

The Unit of Hydraulic Metrology (UHM) is a R&DI infrastructure jointly coordinated by the Department of Hydraulics and Environment (DHA) and the Scientific Instrumentation Centre (CIC) of the National Laboratory for Civil Engineering (LNEC), with competence and capabilities to develop research in Hydrology and Hydraulics and to provide traceability to instrumentation and systems applied in a wide range of measurement quantities, namely, flow rate (mass and volumetric), flow speed, volume, level, and precipitation.

The laboratory infrastructure (Figure 1) has several hydraulic test benches allowing to establish different conditions to obtain flow rate by the primary gravimetric measurement using two weighing platforms (reaching 3 ton and 30 ton) and the measurement of time using universal time counters, all traceable to the primary standards of IPQ (Portuguese Institute for Quality, the Portuguese National Metrology Institute). The main experimental facility as the following operational capabilities:

- volumetric flow rate ≤ 0.500 m^3/s;
- mass flow rate ≤ 400 kg/s;
- nominal diameter ≤ DN 400;
- maximum operating pressure ≤ 1.0 MPa;
- power ≤ 250 kW of electric power groups;
- power ≤ 75 kW for electric pumps not coupled to drive motors.

This Unit supports the skills that allow LNEC to be a Designated Institute for the flow rate and flow speed for liquids, according to the international recognition awarded by the BIPM in 2021 and confirmed by EURAMET in 2022. The management of UHM is developed according to the LNEC Quality Management System complying with the requirements of the ISO/IEC 17025 standard [1].

The R&DI develops methods and apply processes to develop traceability and metrological characterization related with several other types of measuring instruments, namely, ultrasonic flowmeters, turbine meters, positive displacement flowmeters, differential pressure flowmeters, rotameters, mass flowmeters, Parshall flumes, among others [2-5].

This infrastructure has human resources and technologies capable of promoting hydraulic metrology services and metrological information management, in a variety of areas of water resources management (water supply, undue inflow, agricultural uses and wastewater treatment), and in different frameworks (management entities, industry, manufacturers, and customers).

Figure 1: UHM infrastructure overview

2.1. Experimental installation description

The experimental installation was initially created in 1992, for: (1) flowmeters calibration; (2) performance evaluation of centrifugal pumps and (3) performance evaluation of a variety of hydromechanical components of importance to the water industry [6,7]. This infrastructure (Figure 2) has 5 variable speed drives (V1 to V5) with power ratings ranging from 5.7 kW to 250 kW, with 3 main pumps (P1 to P3) and several hydraulic test benches with water ducts nominal diameters ranging from 80 mm to 350 mm. The water is fed from a 350 m^3 underground reservoir and is equipped with 2 main water tanks installed in a weighing platform (used for the gravimetric method). This facility can deliver up to 400 L/s flow rate and a max 6 bar for water pressure.

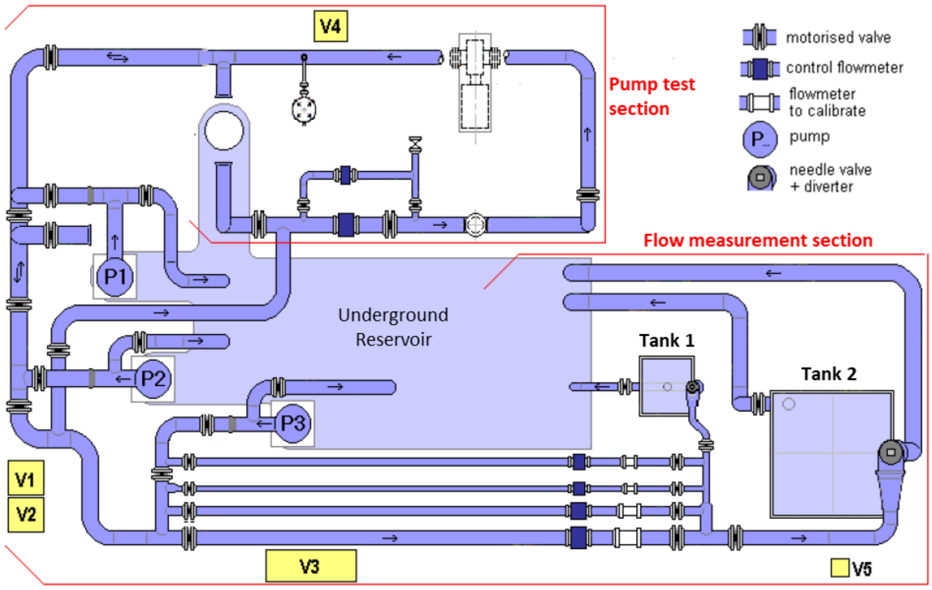

Figure 2: UHM simplified hydraulic infrastructure overview [7]

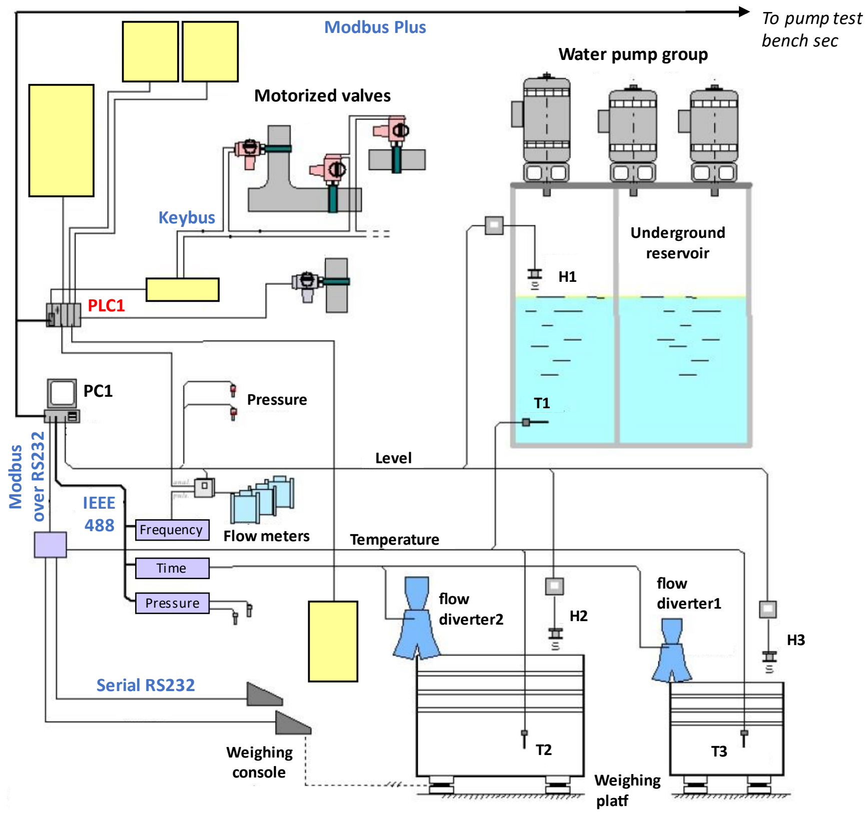

Figure 3: Flowmeters measurement section and legacy automation and control system architecture [6]

The laboratory facility it's also equipped with more than 30 motorized valves, a plethora of electromechanical devices (e.g. flow diverters for rapid water flow deviation) and several high-quality measurement instruments and devices (e.g. flow, pressure, temperature, mass, time).

The automation systems consist of various fieldbus networks and protocols used to integrate the set of heterogeneous equipment and devices—required to measure, automatic control and monitor the safety aspects of the facility.

The flowmeter's measurement section is targeted to perform either gravimetric or reference flowmeter calibration methods. The system is composed of a diversity of devices and field buses (Figure 3). The control and monitoring of this infrastructure—where reliability and security are mandatory—relies on a Programmable Logic Controller (PLC) interconnected with Modbus Plus industrial field bus. PLC1 (Figure 3) is a Modicon model A984-145 and implements: (1) the command for the 3 main pumps P1 to P3 (from the variable speed drives V1 to V3); (2) the command of the motorized valves; (3) the command for the flow diverters (from variable speed drive V5); and also, (4) a closed loop flow control system. Several high-quality measurement instruments are networked with standard field buses (Modbus and IEEE488) and connected to the PC1 with the SCADA system that implements the Human Machine Interface (HMI).

The HMI for all devices, as well as the control and monitoring of this infrastructure, is done through a SCADA system that is installed in a local PC dedicated to these tasks. The SCADA software, which runs in a legacy Windows Operating System (OS), was developed in Visual Basic (VB). The software was tailored to the above-described automation systems to perform the flowmeters calibration processes either by the gravimetric or the reference flowmeter methods (Figure 4).

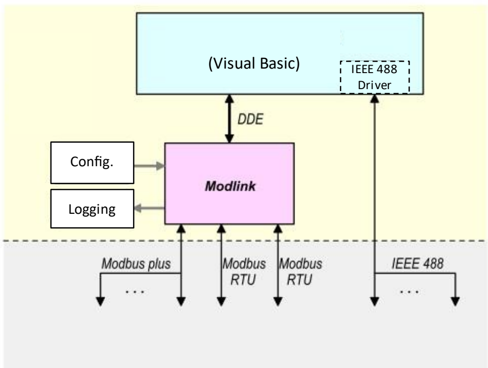

Figure 4. Legacy SCADA implementation in a monolithic architecture

The Modlink [8] software implements a synchronous communication protocol between the Modbus Plus and Modbus RTU (Remote Terminal Unit Modbus protocol over RS323) and the DDE logic protocol. Modlink is a proprietary software solution that enables protocol abstraction between the physical protocols (field bus) and logic protocols compliant with VB. The IEEE488 communications is implemented within VB routines and provides the communication to the high-quality measurement instruments in the infrastructure.

3. LEGACY SYSTEMS LIMITATIONS

In general, the machinery hardware in this kind of infrastructure has long life cycles (more than 20 years) and can be extended if maintenance programs are conducted regularly. This is often true, as legacy industrial communication field protocols (e.g. Modbus) are still used in modern industrial design and integration solutions.

However, the software counterpart tends to be obsolete if not subjected to continuous updates (e.g. due to the obsolescence of the native OS's). Software obsolescence is normally the bottleneck for the modernization and upgrades of this type of legacy infrastructure [9], especially the SCADA system, which usually depends on compatibility with an outdated OS.

In this case, the legacy SCADA program was developed in a monolithic approach, where all field protocols needed to integrate in this software, to concentrate all remote resources and operationality of the infrastructure in one single unit or PC. This was often the design and integration philosophy back in the days. However, one major drawback of this approach is the dependency on one single unit or software, especially when field protocols (e.g., RS232) does not allow multiple drop host in the network. Additionally, the centralized architecture makes the system dependent of a single point of failure. Also, the centralized storage architecture makes it vulnerable to data loss.

One of the most restrictive features of the current implemented architecture, resides on legacy proprietary field protocols (e.g. Modbus Plus and Keybus), as it depends on proprietary specific software (e.g. Modlink) and hardware (e.g. SA85 and Busmaster network interfaces). Additionally, legacy proprietary protocols tend to be deprecated by obsolescence, making future modernization and upgrades difficult and sometimes impossible.

The logic protocol DDE was another limitation that was found in this architecture—a Windows-specific protocol, deprecated after Windows XP SP2, preventing future upgrades of the OS used for the SCADA system.

On the other hand, legacy standard protocols are not vendor specific and are usually adopted in a variety of new hardware and software, including open-source solutions. Therefore, future architecture, design and integration should consider standard protocols, standard field bus, and avoid proprietary ones. This can benefit future upgrades and modernization of the overall system.

4. DISTRIBUTED SYSTEM INTEGRATION

The emergence of modern technologies and applications, requires the automated creation, processing, and updating of the calibration certificates [10]. In this context, to enable an automated calibration procedure, the system architecture, by design, must allow the auditability of the entire process. Beyond the functional requirements (what it should do), the system has also to meet some vital nonfunctional requirements: reliability (maintain operation in the presence of faults), scalability (maintain performance when load increases) and maintainability (having effective ways to manage the system and access system's health) [11].

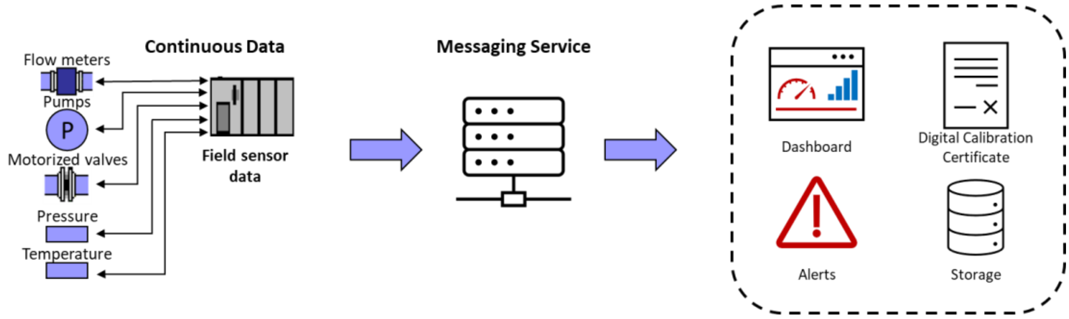

Figure 5: Data streaming and messaging service distributed architecture

Towards the modernization of this legacy infrastructure, the innovative approach adopts a distributed architecture (Figure 5). As opposed to the current monolithic approach—where all communications are concentrated in one single master unit—, the proposed method aims to provide, through standard TCP/IP protocols, remote access to all distributed devices and subsystems resources. As already stated, the advantage of using standard protocols relies on the acceptance of vendor-free hardware and software fostering new upgrades. Embracing the widely used internet protocols also enables a more flexible communication integration toward a distributed architecture system.

Additionally, this approach also facilitates a modular system integration architecture, enabling the progressive design of a new and modular SCADA system integration without decommissioning current legacy SCADA software. This approach also allows the implementation of redundancy in the current SCADA system, which was not feasible previously.

However, aspects involving the reliability and security of this infrastructure must be considered, specifically the devices controlled directly from the PLC1.

4.1. Linkage of the legacy PLC systems with TCP/IP networks

In this section, the proposed solution for interfacing a legacy PLC in this new distributed architecture is described—towards industry 4.0 systems, IIoT devices, modern information storage and access.

The described PLC1 lacks any TCP/IP ports or connectivity. However, it has 2 communications ports built in (Figure 6), one for proprietary protocol Modbus Plus (port1) and another for standard protocol Modbus (port2). The first port is currently in service to connect to the legacy SCADA system (Figure 4). The second port is avaiable to link any peripherals that can implement the standard Modbus protocol (over a standard serial RS232 interface) in a single master-slave topology.

To link the PLC1 to a TCP/IP network, a single board computer (SBC) is used (Raspberry Pi model 4 with 2 GB of RAM). This SBC has several physical interfaces (Ethernet, USB, GPIO) and enough computing power to provide a continuous sensor data stream. The SBC serves as a gateway between PLC1 and the TCP/IP network, providing PLC1 field sensor data over the TCP/IP network.

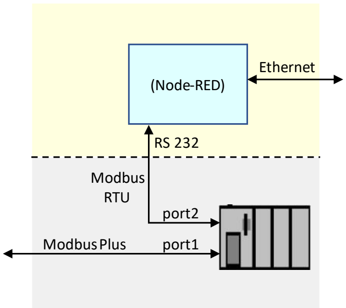

Figure 6: Message broker architecture

The gateway is implemented with Node-RED open-source software instance, installed in the SBC. Node-RED is a web browser-based visual programming tool compliant with several protocols including Modbus and TCP/IP. Since Node-RED is a web-based program, it provides access to PLC1 with standard internet protocol, enabling a more flexible communication and configuration of this device, that was not feasible previously.

Additionally, the Node-RED acts as the master in the Modbus communication with the PLC1 and provides a data stream (flow), through TCP/IP, to the message broker [12, 13] in a publish/subscribe model—implemented in Apache Kafka messaging service running in UHM's private cloud.

5. CONCLUSION AND FUTURE WORK

A solution to modernize a legacy infrastructure in a distributed system integration was presented. With cost-effective hardware and open-source software, it is possible to make a gateway between a legacy PLC and streaming messaging system-based standard internet protocols, overcoming the imposed limitation of proprietary legacy field bus protocols and communications.

The implemented message service architecture enables to access the PLC1 registers (and therefore the field sensor data and devices) over the standard TCP/IP network, allowing the implementation of a new and more flexible web-based SCADA system.

By integrating the Apache Kafka software, the proposed method provides a distributed system architecture, capable of integrating new services and devices, and also distributed data storage. Additionally, being a widely accepted open-source solution, with high volume performance, clustering and reliability, this architecture fosters future upgrades and interoperability of this infrastructure without special hardware.

One key aspect of the proposed method is the scalability of the system with cost-effective and available modern digital technologies. The publish/subscribe model simplifies the introduction and implementation of new digital ecosystems and tools, towards the industry 4.0 era, e.g. in implementing the Digital Calibration Certificates, optimization of the infrastructure maintenance procedures, cloud computing architectures, etc. Additionally, the proposed method applied to other infrastructure legacy devices allows the seamless integrations of the diverse heterogenous field protocols in a single and unified messaging service.

Future work addresses the limitations of the legacy Keybus field bus and associated Busmater network interface, for remote actuation and monitoring of the 36 motorized valves on the infrastructure. The main goal is to integrate the motorized valve's communications in the publish/subscribe model architecture. This allows the implement the remote actuation through internet protocols and enables to manage the time-of-service of each individual valve. This last aspect is especially important for maintenance optimization implementation, given the importance and intensive use of these devices in the infrastructure. However, given the number of motorized valves in question, it is not cost-effective to use one SBC for each valve, and thus other solutions (e.g. using microcontrollers) should be explored.

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