

Optimizing the Lab Automation Workflow using OPC UA and Allotrope Simple Model (ASM)

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Abbreviations and Acronyms

LADS: Laboratory and Analytical Device Standard

OPC UA: Open Platform Communication Unified Architecture

SiLA: Standardization in Lab Automation. Developed by the SiLA Consortium.

Allotrope Foundation: An international consortium of pharmaceutical, biopharmaceutical, and other research-intensive industries.

CDS: Chromatography Data System

LIMS: Lab Information Management Systems

ERP: Enterprise Resource Planning

HPLC: High Performance Liquid Chromatography

AniML: Analytical Information Markup Language

ISO/IEC 17025:2017: An international standard that defines the general requirements for the competence of testing and calibration laboratories.

Sample Method: Sample Method refers to a defined protocol or set of instructions used to handle, prepare, and analyse a sample.

Abstract

Although ISO/IEC 17025:2017 doesn't define interoperability protocols directly, but it encourages the use of Standardized data formats that facilitates integration with systems like SiLA2, OPC UA and Allotrope ASM.

This paper mainly presents how lab automation optimization can be achieved by integrating OPC LADS with the Allotrope Semantic Model (ASM), enabling standardized, semantically enriched communication between laboratory devices and enterprise systems.

Scope of the paper

Scope of the paper covers below details

- Current lab automation software layer and its challenges.
- Introduction of OPA UA with LADS Information model
- Plug-and-play interoperability using OPC UA (Device-type agnostic model)
- Importance of Semantic IDs
- Introducing ASM (Allotrope Semantic Model)
- Achieving machine readability in Lab Automation using ASM

Scope Exclusion

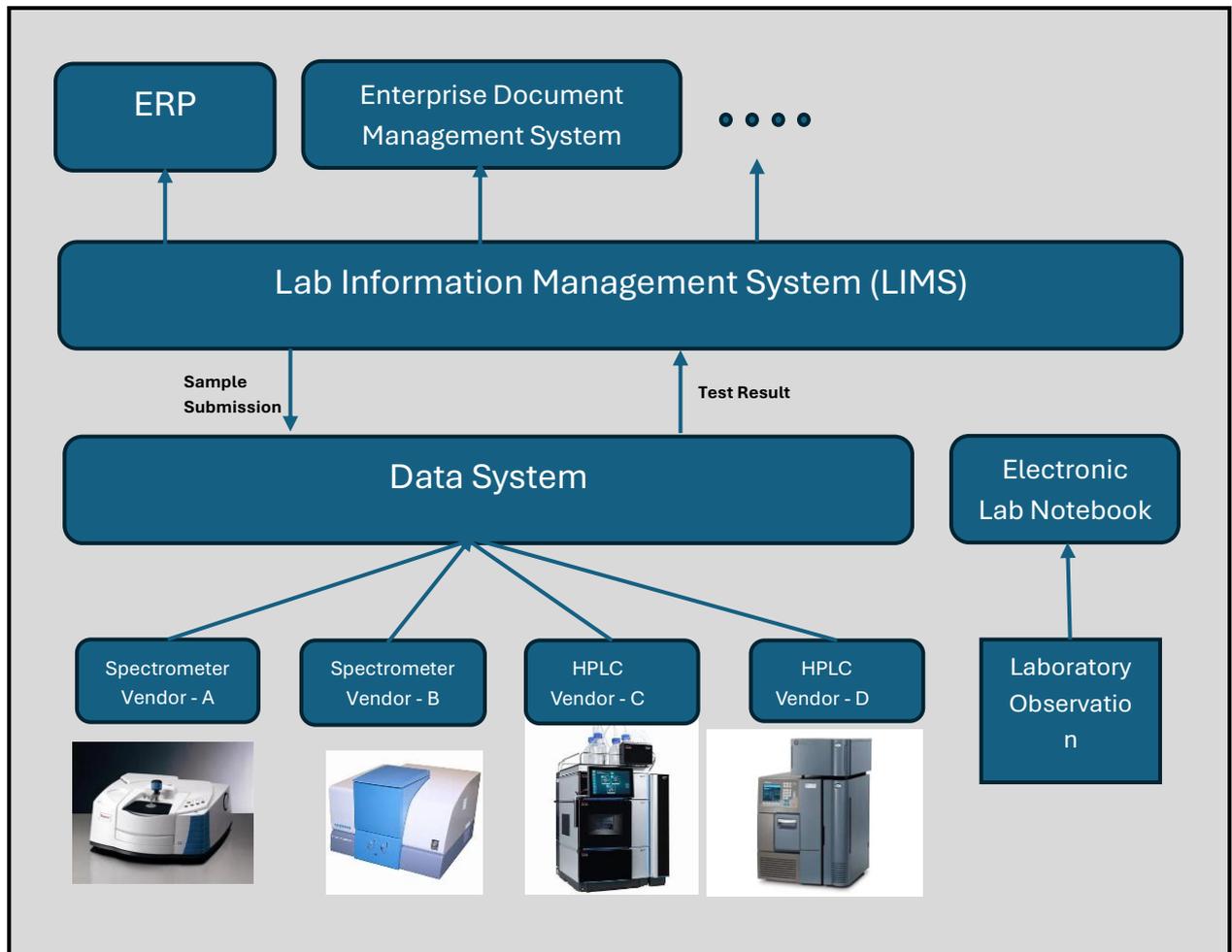
- Scope of the paper does not include any comparison or information related to other laboratory Automation standards like SiL2, AniML etc.
- Scope of the paper is limited to the specific lab automation use cases using OPC UA LADS Server and ASM
- Scope of the paper does not validate the conformance of ISO/IEC 17025:2017 requirement

Typical Lab Automation Workflow

After Patient examination, medical practitioner prescribes the lab tests which will be entered into the LIMS system after the collection of samples (blood, urine etc.).

Below Figure - 1 shows the technical workflow after receiving the Sample.

Figure 1 - Technical Workflow of Lab Automation Software Layers



LIMS System will receive the “Sample Submission”, which will be sent to the **CDS (Chromatography Data System)**. CDS will acquire necessary data like (Sample ID, Test Code, Timestamp etc.) and will be sent to Analyzer system for analysis. After receipt of the data from underlying analysers including Measured Value, Sample Method etc. Data will be processed, analysed and assigned result to samples and sent to LIMS to trigger the workflow. This marks the complete workflow of sample submission from LIMS System to acquiring the Test Result by LIMS.

Typically, HPLC Systems comes up with their only device driver/custom software which needs to be integrated into CDS System. Any new HPLC system from other supplier needs update to CDS System

Analytical Instruments like Chromatographs, Analysers needs to connect to CDS via custom device drivers. So, addition of any new supplier’s instrument requires major update to CDS system.

OPC UA LADS Server

The OPC UA - Laboratory and Analytical Device Standard (LADS) is a companion specification to OPC UA. It designed to enable seamless, manufacturer-independent communication between laboratory devices and software systems.

As shown in below figure-2, OPC UA - LADS specification (OPC 30500-1) is built on top of OPC UA companion specification for Analyzer devices (OPC 10020). Optionally, Instrument Supplier can build vendor specific information model on top of OPC UA - LADS. Allotrope Semantic IDs can be incorporated into the OPC UA – LADS Information model which will be discussed in a subsequent section of this white paper.

OPC UA LADS Information Model

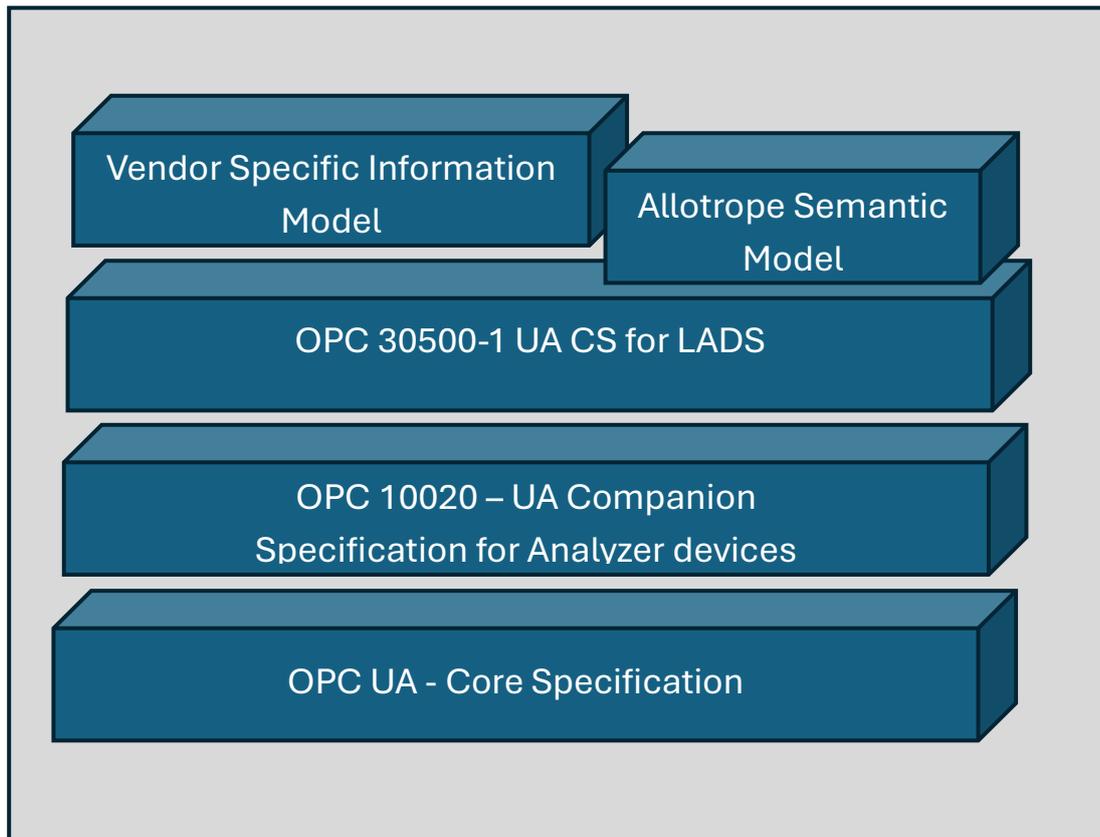


Figure 2 – OPC UA Information Model

OPC LADS Information Model can be categorized as

- Device Model
- Functional Units
- Program Manager
- Asset Management
- Notification & Monitoring

Device Model: Lab and analytical devices are defined by two views, the Hardware View and the Functional View.

The Hardware View focuses on the physical aspects of the devices such as nameplate, installation dates, calibration status and hardware component like lid, rotor, drive & compressor. etc. and their components focussing on asset management.

It also provides device-agnostic framework, meaning it can represent a wide variety of instruments without being tied to the supplier or device-type.

For example: As shown in below figure - 3, device types like Spectrophotometer and Thermal Analyzer devices are represented using the OPC UA LADS Information model. However, the object instance of these types will have device type specific values.

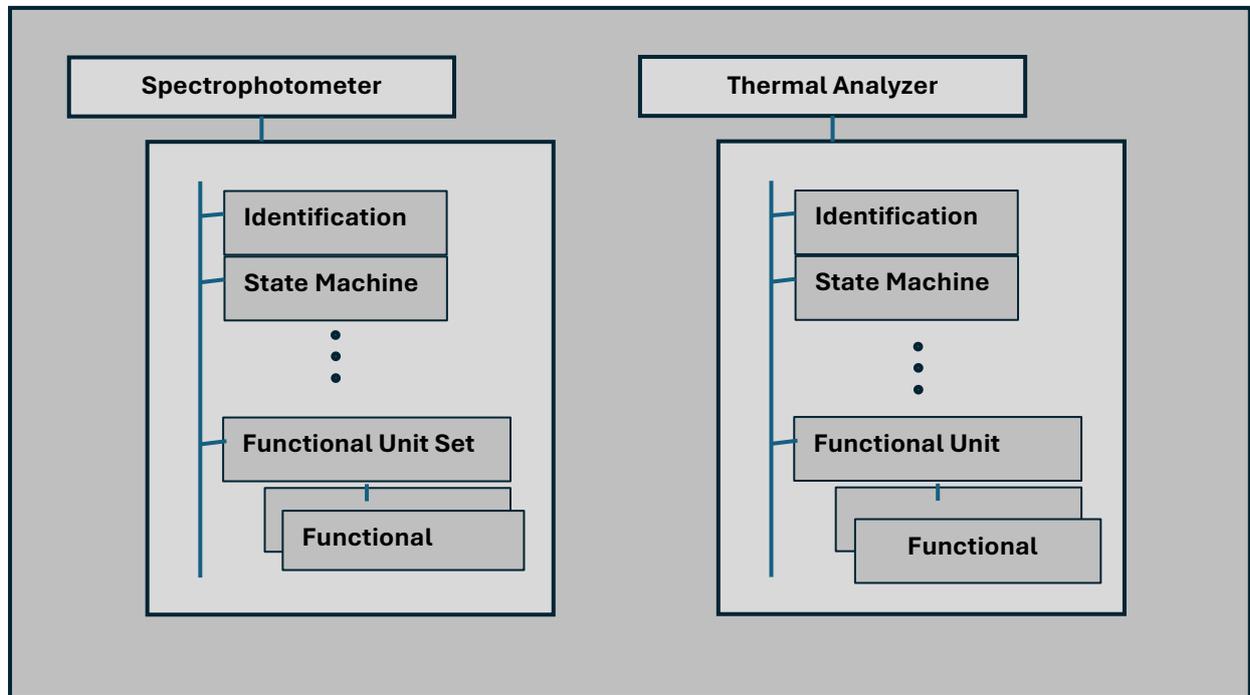


Figure 3 – Information model representation different device type

The Functional View of Device Model deals with data relevant for the operations, automation and orchestration.

Functional Units: Functional unit is like virtual device within a LADS device. It is basically aggregation of functions designed to achieve specific outcome.

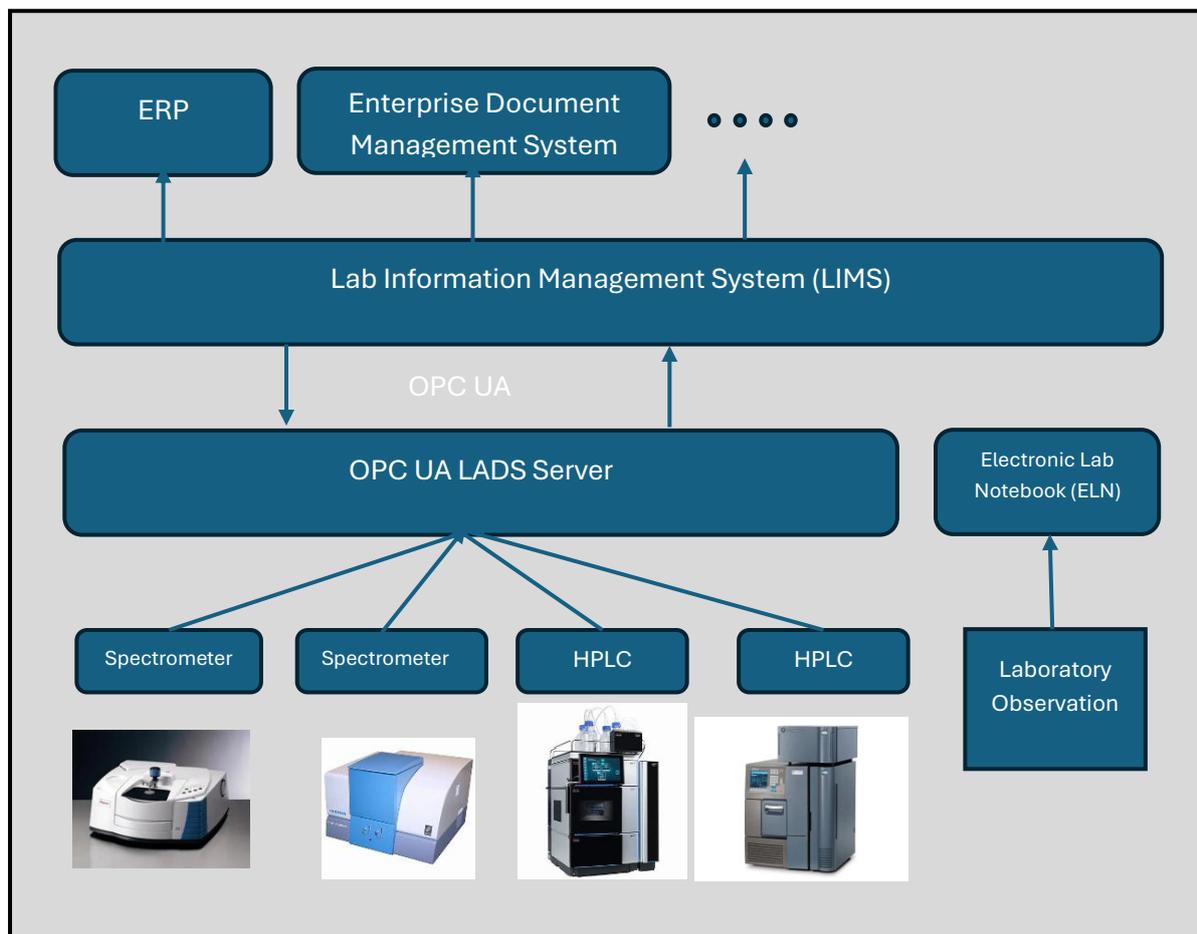
Program Manager: Many laboratory and analytical devices allow the user to define and run programs, also called methods. The Program Manager organizes program templates, runs programs, and manages the result data generated during a run, providing device-level orchestration.

Asset Management: This includes the services related to Asset Management like condition monitoring & maintenance, location etc.

Notification & Monitoring: Any automation includes the remote monitoring, alarms and events and handling the notifications. In LADS Information model, remote monitoring use case can be achieved by Alarm & Notification functionalities, where user will be notified when the observed property values goes out of limits.

Lab Automation Software Layer with OPC UA - LADS

As depicted in figure-1, in the typical lab automation software layer, integration of any new devices requires major update to CDS System. This can be optimized, and plug and play of any new instrument of any type and any supplier can be achieved by integrating OPC UA – LADS Information model as shown in below figure.



Laboratory Devices such as analysers, balances, or chromatographs generate raw data during sample analysis. These devices are equipped with or connected to an **OPC UA Server** that implements the **LADS Information Model**. This will be integrated into the LIMS System via OPC UA interface.

The OPC UA Server exposes device data like measured value, device status, Sample ID, Sample method etc. in a **standardized format** defined by the LADS companion specification. LADS Information model provides a semantic structure for the data. It defines how devices, methods and results are represented which ensures consistency across different supplier and device types. Plug & play of any instrument into Lab automation workflow can be achieved using OPC UA.

Machine readable Semantic IDs

In order to achieve interoperability, traceability and intelligent data exchange, machine readable Semantic IDs are essential in automation. Semantic IDs are standardized unique identifiers and related meta data information. These IDs are machine-readable.

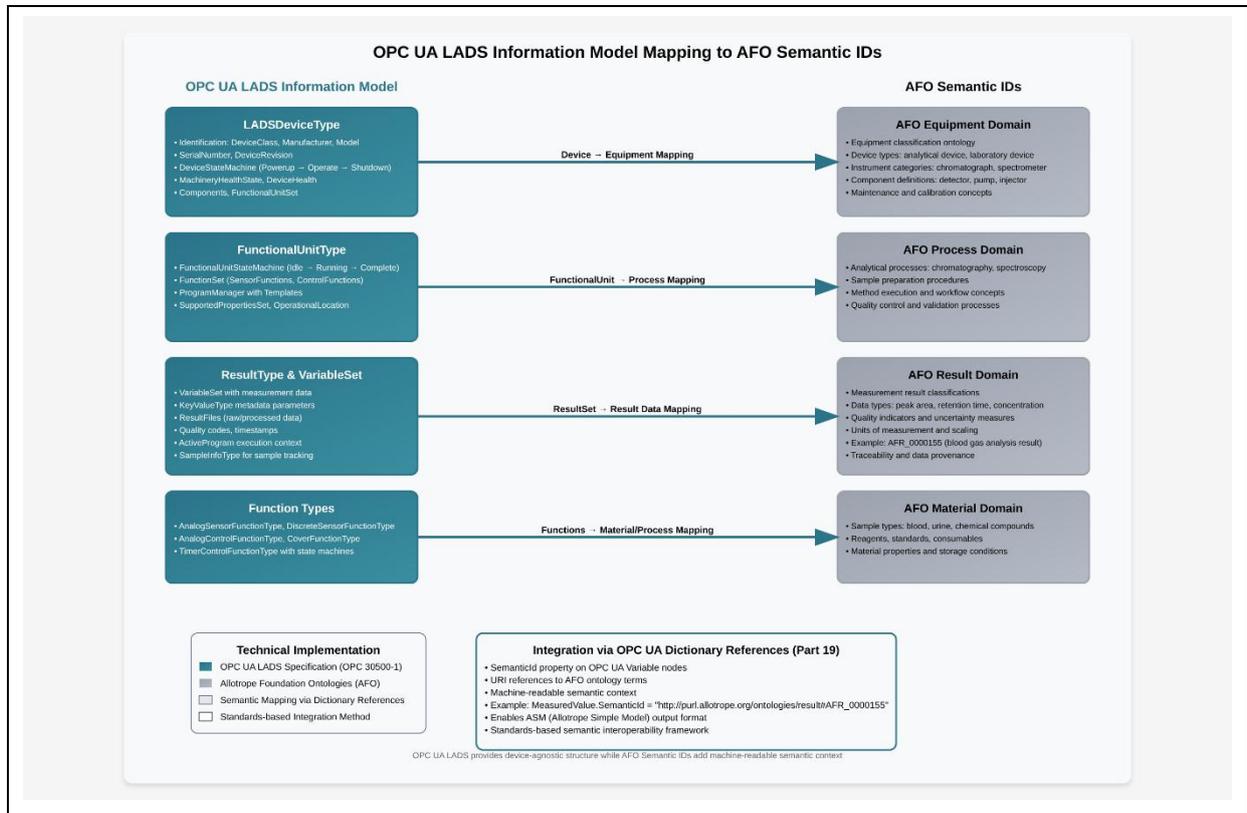
Introducing Allotrope Semantic Model - ASM

The **Allotrope Semantic Model (ASM)** is part of a broader framework developed by the Allotrope Foundation to standardize and enrich laboratory data through semantic technologies. It's designed to make analytical data more interoperable, traceable, and machine-readable across diverse lab environments.

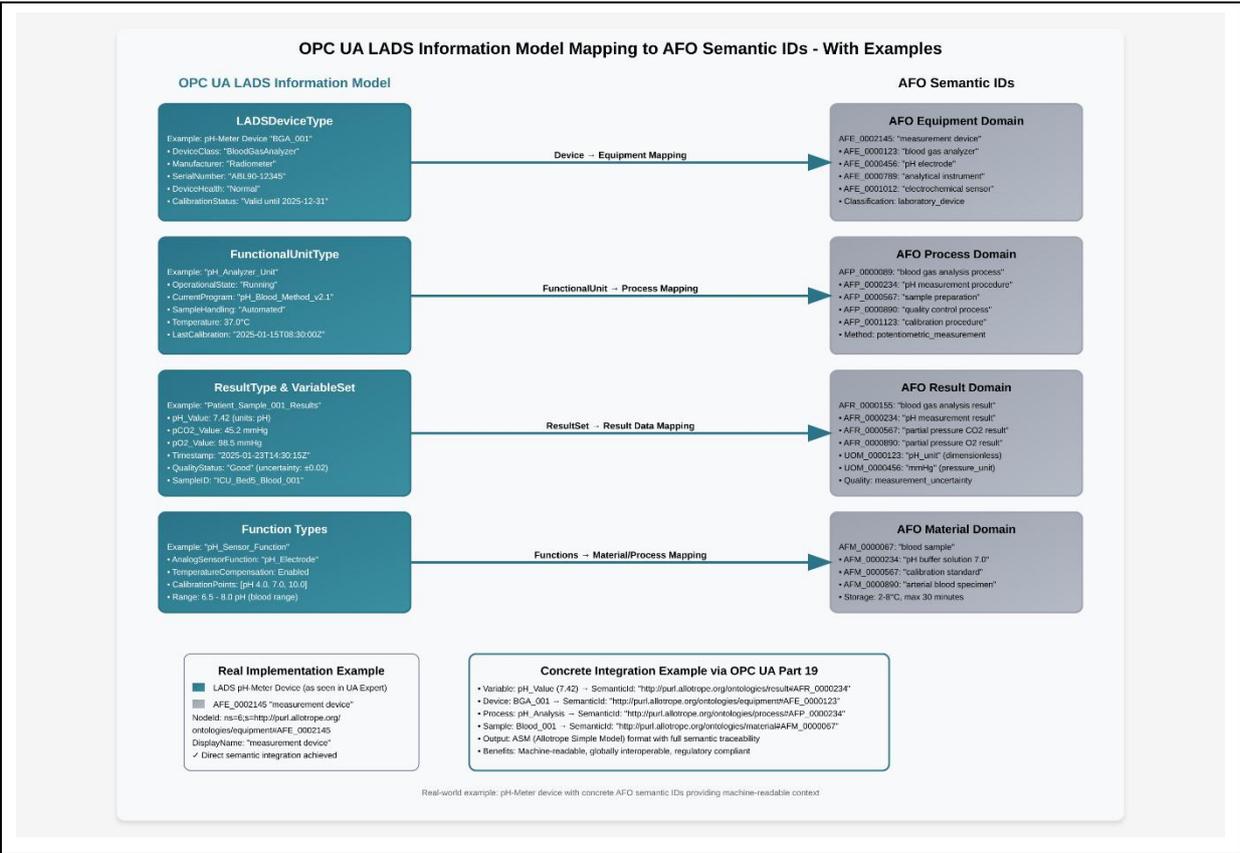
Below table-1 represents the Semantic IDs of 'blood gas analysis result'.

<p>PrefLabel : <i>blood gas analysis result</i></p> <p>AltLabels: <i>blood gas measurement result; BGA result</i></p> <p>Domain: <i>bga</i></p> <p>TermType: <i>result</i></p> <p>Definition: <i>The measurement result of analysis from a blood gas analyzer. [Allotrope]</i></p> <p>TermIRI: <i>http://purl.allotrope.org/ontologies/result#AFR_0000155</i></p>

Mapping of AFO Semantic IDs to OPC UA -LADS Information Model



As shown in above figure OPC UA LADS information model components mapped to AFO semantic domains, showing the technical framework for integrating device-agnostic laboratory automation with machine-readable semantic context through OPC UA Part 19 Dictionary References.



As shown in above figure OPC UA LADS information model components mapped to AFO semantic domains, demonstrated with real devices examples showing how device data gains machine-readable semantic context for laboratory automation interoperability.

Address Space

- NodeVersion
- pH-Meter Unit
 - FunctionSet
 - Temperature Sensor
 - CalibrationValues
 - IsEnabled
 - Operational
 - RawValue
 - SensorValue
 - pH Sensor
 - FunctionalUnitState
 - Lock
 - Program Manager
 - Simulator
 - HardwareRevision
 - Identification
 - MachineryItemState
 - MachineryOperationMode
 - Manufacturer
 - Model
 - ProductInstanceUri
 - RevisionCounter
 - SerialNumber
 - SoftwareRevision

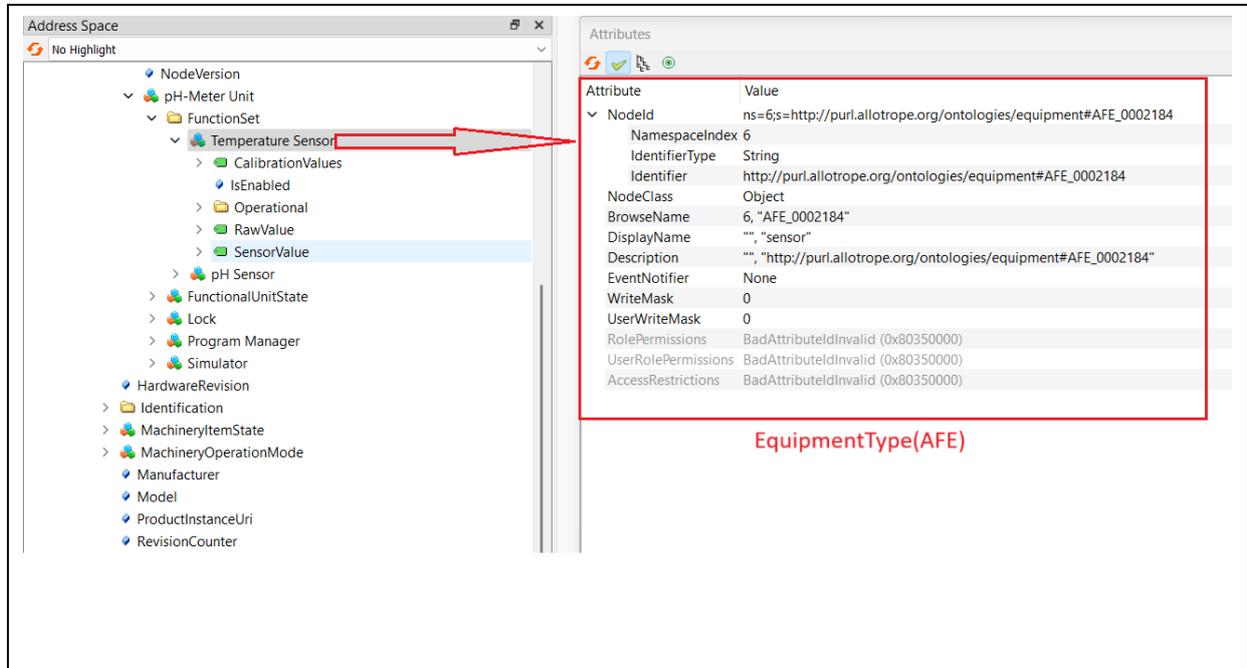
Attributes

Attribute	Value
NodeId	ns=6;s=http://url.allotrope.org/ontologies/process#AFP_0003541
NamespaceIndex	6
IdentifierType	String
Identifier	http://url.allotrope.org/ontologies/process#AFP_0003541
NodeClass	Object
BrowseName	6, "AFP_0003541"
DisplayName	"" "temperature measurement"
Description	"" "http://url.allotrope.org/ontologies/process#AFP_0003541"
EventNotifier	None
WriteMask	0
UserWriteMask	0
RolePermissions	BadAttributeValue (0x80350000)
UserRolePermissions	BadAttributeValue (0x80350000)
AccessRestrictions	BadAttributeValue (0x80350000)

ProcessType(AFP)

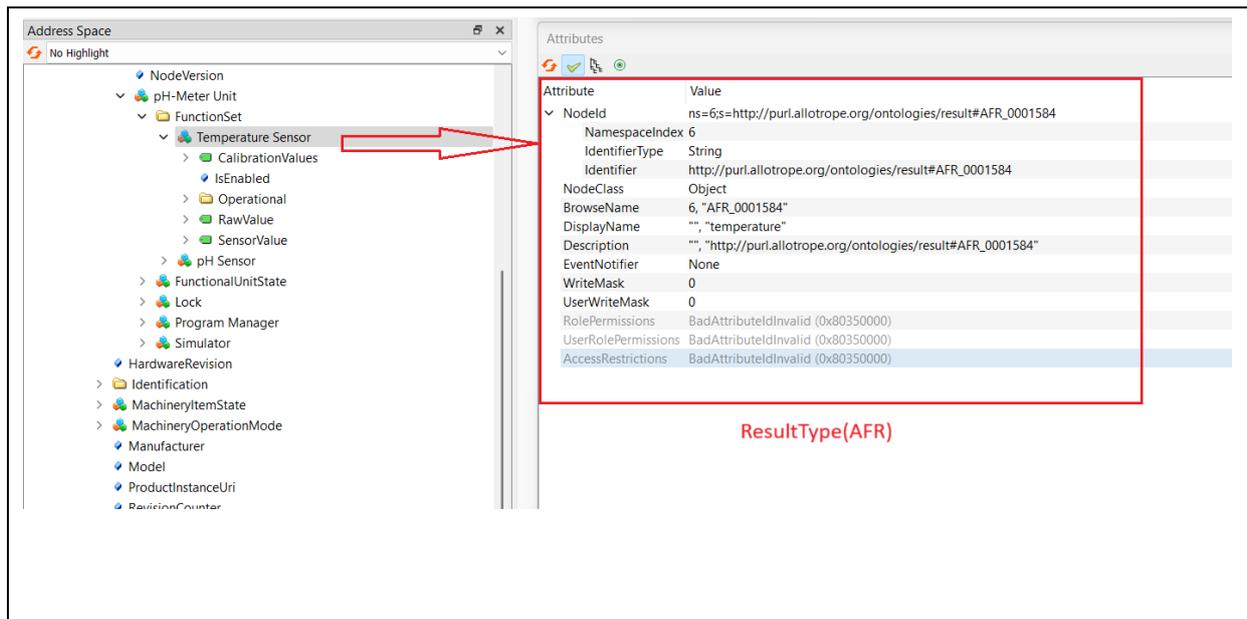
As shown in above figure OPC UA client view showing AFO Process Domain semantic ID implementation in a 'pH-Meter' LADS server.

The Temperature Sensor node demonstrates direct semantic integration with NodeId containing the AFO Process ontology URI (AFP_0003541) for "temperature measurement", illustrating how LADS functional components are semantically enhanced with Allotrope Foundation ontology identifiers for machine-readable laboratory automation.



As shown in above figure OPC UA client displaying AFO Equipment Domain semantic ID integration in a LADS pH-Meter server.

The Temperature Sensor node shows direct semantic mapping with NodeId containing AFO Equipment ontology URI (AFE_0002184) for "sensor", demonstrating how LADS device components are enhanced with standardized Allotrope Foundation equipment classifications for interoperable laboratory automation.



As shown in above figure OPA UA client showing AFO Result Domain semantic ID implementation in a LADS pH-Meter server. The RawValue node demonstrates semantic integration with NodeId containing AFO Result ontology URI (AFR_0001584) for "temperature" measurement results, illustrating how LADS measurement data is enhanced with standardized Allotrope Foundation result classifications for machine-readable laboratory data exchange.

Conclusion

Laboratories face increasing demands for data standardization, automation, and regulatory compliance. OPC LADS, built on OPC UA, provides a unified communication framework for laboratory devices. Semantic IDs ensure that different systems (e.g., LIMS, MES, ERP, SCADA) understand each other's data. For ex: "molar concentration" from one device is recognized as the same concept by another system, regardless of supplier. It also allows integration of new device type or same device from other supplier easily. Semantic tagging also helps track the origin, transformation, and usage of data. Semantic IDs allows optimization of lab automation by enabling contextualized analysis of information, data traceability & compliance.

Acknowledgment

This white paper draws upon specifications, reference implementations, and community-led initiatives that promote interoperability in lab and analytical environments. Special thanks to OPC Foundation, Allotrope Foundation and its available resources, Contributors and chairman of OPC UA - LADS Companion Specifications.

About Authors

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OPC Foundation Accredited Expert (<https://opcfoundation.org/about/opc-foundation/experts/>). Founder of OjasQuest, Smitha has 20+ years of experience in Industrial Automation domain and entrepreneurship. She has expertise in Industrial standards like OPC, EtherNet/IP, FDT, FDI, NAMUR etc. She has contributed to various OPC UA Companion Specifications like FDT OPC UA Companion Specification, FDI Information Model, PA-DIM, CIP OPC UA mapping. She has authored book on OPC UA and written multiple IEEE publications and white papers. She is Speaker and Panellist in multiple Industrial forums. She has done master's from BITS Pilani and Computer Science Engineering from MIT, Manipal.

Vijay Kadkol:

Director of Enterprise Solutions at OjasQuest, Vijay has ~20 years of experience in building the industrial software solutions. He has good experience and knowledge in communication standard like OPC, FDT, EDDL, HART, Modbus etc. He has architected various enterprise solution, machine critical applications. He is also TOGAF certified practitioner.

Praveen Godekar:

Praveen has over 5+ years of experience in developing industrial software solutions, with a strong focus on OPC-based architectures (including OPC UA and OPC Classic) and AI/ML-driven applications. He has a deep understanding of the OPC UA specification, information modelling, and DTM integration. Praveen is skilled in developing cross-platform applications and has hands-on experience with industrial communication protocols such as HART, Modbus, BACnet, and Ethernet/IP. He holds a degree in engineering from NIE, Mysore, and specializes in building scalable, robust systems that connect legacy equipment with intelligent, modern automation platforms.

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[210408_LADS_Whitepaper_ENG.pdf](#)

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OPC UA Specifications

- OPC UA 10000-1: Overview
- OPC 10020: Analyzer Devices
- OPC 30500-1: Laboratory and Analytical Devices
- OPC 30270: Industry 4.0 Asset Administration Shell
- OPC 10000-3: Address Space Model
- OPC 10000-5: Information Model

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