Ontologies for the Generic Motor Winding Process

Motor Winding Process Ontology (MWPO)

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ABSTRACT

Integrating information technology (IT) and operational technology (OT) in the manufacturing ecosystem is crucial for improving productivity, efficiency, and situational awareness. However, integrating various IT/OT systems is often time-consuming and expensive. Semantic integration resolves this by unifying data from heterogeneous sources while preserving the contextual meaning of each source. The success of semantic integration requires robust ontologies that describe objects, processes, and relationships for knowledge representation, system integration, and semantic interoperability. Despite the significance of ontologies in many industrial domains, a scientifically defined ontology for the motor manufacturing process is in demand.

This research addressed this gap by applying the top-down approach with 5M (manpower, machine, method, measurement, and material) methodology to develop a generic motor winding process ontology systematically. Encoded in the Terse RDF Triple Language (TTL), the developed ontology systematically addressed the needs of diverse job roles by incorporating fundamental aspects such as motor types, winding techniques, and thermal classes. The ontology consisted of a clear definition of core classes and their relationships, and outlined the major factors influencing the motor winding process. Finally, validation experiments confirmed the robustness of the ontology through syntax validation, logical validation using "HermiT" reasoning, domain compatibility assessments via competency questions, and SPARQL query execution outputs. The results confirmed the robustness of the ontology and its applicability, offering a framework for semantic interoperability and knowledge representation in the motor winding process.

1. Introduction

With the increasing demand for motors and the advancement of modern information technology (IT) and Operation Technology (OT), commercial manufacturers must refine the motor winding process to boost efficiency and optimization [1,2]. The winding process should be improved with modern smart technology in manufacturing, utilizing Industry 4.0 standard features [3]. Similar to many manufacturing environments, the motor winding process utilizes a variety of IT/OT systems [2]. Integrating these applications enhances the accuracy of situational awareness for decision-making, process optimization, and forecasting [3]. This paper proposes integration relying on the meaning of the data, which is called semantic integration. Semantic integration is aligning the meaning of data from different sources relying on shared vocabularies/ontologies and mappings, hence the combined data can be queried and used coherently [4]. Semantic integration requires a standard knowledge that defines the relationships between concepts, terms, and data within a considered domain; this knowledge representation can be presented using ontologies [5]. Integrating IT/OT systems semantically requires an ontology for the motor winding process. This paper aims to develop an ontology for the generic motor winding process to enhance application interoperability, situational awareness, and process optimization.

Ontology, originally a branch of philosophy, is widely used in knowledge representation to describe both physical and virtual entities in a structured form [6,7]. For instance, describing a television requires a description of properties such as size, shape, colour, sound, and category. Providing more properties with values allows a better understanding even without accessing the object. Modern research shows that automated factories require an ontology to represent the manufacturing process using a structured knowledge representation for semantic interoperability, process optimization, robotic automation, and intelligent decision-making [8,9]. Ontologies provide a standardized vocabulary in the manufacturing process and improve interoperability between software applications like Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and Warehouse Management Systems (WMS) [10]. Introducing new ontologies for the manufacturing process is a trend in modern industrial research to obtain the benefits

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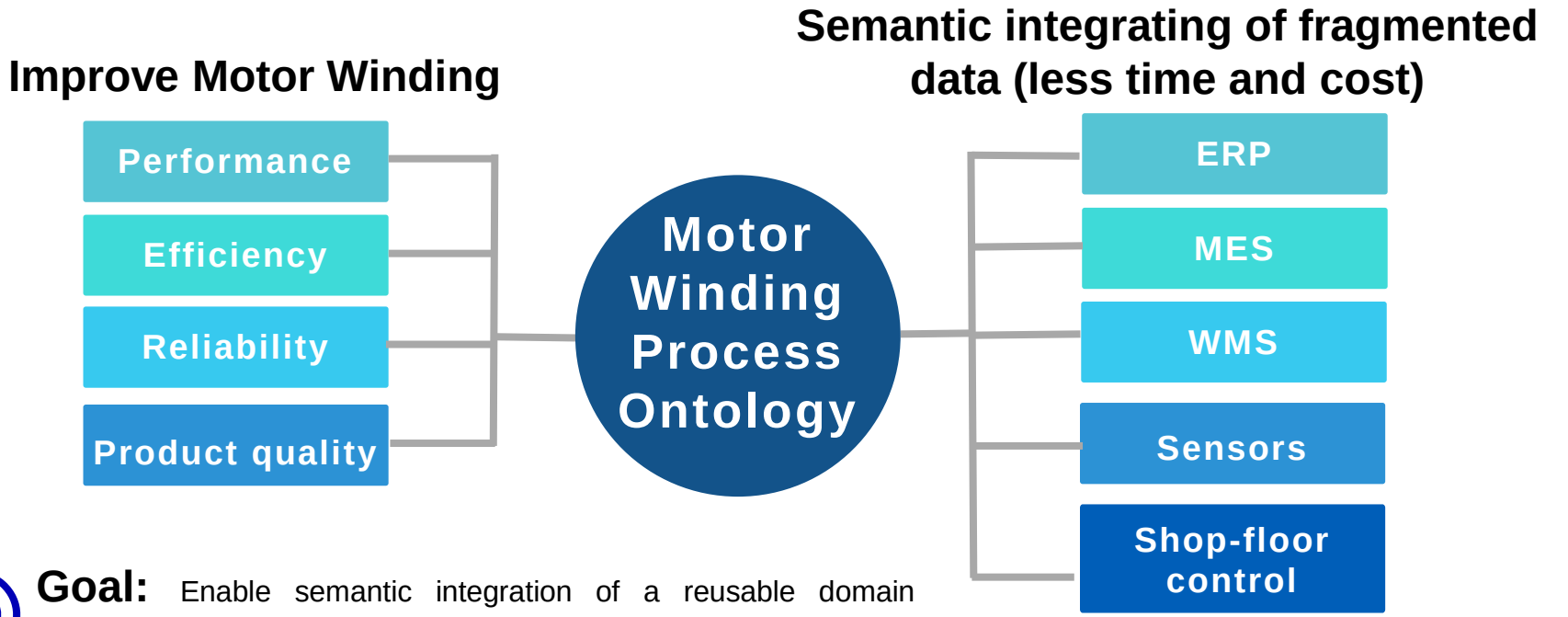
Why motor winding needs a shared meaning layer



Goal: Enable semantic integration of a reusable domain ontology that lets systems agree on what data means across the motor winding process.

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Method: Motor Winding Process Ontology (MWPO)

A reusable, generic knowledge model for the motor winding process that supports interoperability across IT/OT systems.

Design approach

Top-down modeling

5M framework

- Manpower (skills, roles)
- Machine (assets, states)
- Method (process steps)
- Measurement (tests, QC)
- Material (insulation, wire)

Process coverage

- Core preparation
- Coil winding
- Insertion
- Connections
- Impregnation
- Balancing
- Quality control
- Final assembly

Consideration:
Engineering • Maintenance • Quality • Management • Customer support

Scale & validation

Classes	Relations	Validation pillars
643	1,043	3

1) Logical consistency

Protégé and HermiT reasoner

- 0 unsatisfiable classes
- 10,042 asserted axioms
- 12,317 inferred axioms

2) Domain relevance

20 competency questions answered via SPARQL

- Machine suitability
- Test requirements
- Safety states
- Skills & troubleshooting

3) Practical case study

Material selection (thermal class)

SPARQL vs SQL validation
~312 µs (SPARQL)
~1,255 µs (SQL)

Efficient & semantically richer

Summary

MWPO enables

- Cross-system data federation
- Context-aware operator support
- Predictive quality & analytics
- Digital twin synchronization
- Rule-based validation (e.g., materials, tests, safety)

A generic, validated ontology that supports interoperability and future ontology-driven applications in winding and digital twins.

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Thank You