USING SEMANTIC SYSTEMS ENGINEERING TECHNIQUES TO VERIFY THE LARGE APERTURE SPACE TELESCOPE MISSION – CURRENT STATUS

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INTRODUCTION

MBSE aims to integrate engineering models across tools and domain boundaries to support traditional systems engineering activities (e.g., requirements elicitation and traceability, design, analysis, verification and validation) [1], [2]. However, MBSE does not inherently solve interoperability with the multiple model-based infrastructures involved in a complex systems engineering project. The challenge is to implement digital continuity in the three dimensions of systems engineering: across disciplines, throughout the lifecycle, and along the supply chain [3]. Changes to the system requirements or the design must be propagated automatically through the supply chain to facilitate the swift evaluation of its impact. Documentation, where required, will be generated and updated automatically.

In order to achieve the goal of interoperability, it is necessary to further develop MBSE practices through the formalisation of a global Conceptual Data Model (or ontology) that will contain the project and design information. One way of developing this approach is through the use of modern Semantic Web Technology (SWT). SWTs have emerged over the last decade as a key tool for formal knowledge representation and to achieve semantic interoperability between different modelling artefacts and database architectures using a Linked Data approach [4]. SWTs utilise specifications such as the Resource Description Framework (RDF) [5] and the Web Ontology Language [6] to make data machine-interpretable and to provide it with context. Doing so enables users to automatically reason with the data, infer implicit knowledge, and query the knowledge base. The European Space Agency's (ESA) Overall Semantic Modelling for System Engineering (OSMoSE) initiative is currently working towards the implementation of semantic modelling to achieve semantic interoperability [7].

Space systems are ideal candidates for the application of MBSE and semantic modelling as these complex and expensive systems are mission-critical and often co-developed by multiple stakeholders. In previous work, the authors introduced the Cloud Systems Factory (CloudSF) tool – a continuous integration framework for designing and validating cyber-physical systems [8]. As highlighted in [8], one of the highlights of the CloudSF platform is the use of a global Conceptual Data Model (system ontology). In this paper, the authors introduce the concept of Semantic Systems Engineering (SES) as an expansion of MBSE practices to include semantic modelling through SWTs. The paper also presents the progress and status of a novel Semantic Systems Engineering Ontology (SESO) in the context of a specific design case study – the Large Aperture Space Telescope mission.

USE CASE

25m LAST Assembly Mission Scenario

The use case concerns the in-orbit assembly of a 25m Large Aperture Space Telescope (LAST) [9]. The LAST mission is a highly complex mission consisting of the autonomous, robotic assembly of the 25m Primary Mirror (PM) while in orbit. The PM comprises 18 Primary Mirror Segments (PMS) and each PMS further consists of 19 Primary Mirror Units (PMU). The assembly is performed in a step-by-step manner by two seven-degrees-of-freedom End-Over-End Walking Robots (E-Walker). The mission architecture comprises the E-Walkers and the spacecraft platform. The spacecraft platform includes the base spacecraft (B_{SC}), storage spacecraft (S_{SC}) and the truss structure. The B_{SC} contains the necessary support systems such as the Attitude and Orbit Control System (AOCS), the On-Board Computer (OBC), and the power subsystem. The S_{SC} houses the unassembled, stacked PMUs. The truss structure provides the structural framework onto which the E-Walker assembles the PMUs and PMSs. Connector ports on the spacecraft platform provide the E-Walkers with the necessary data, power and mechanical interfaces as the E-Walkers traverses the spacecraft platform. This mission scenario is presented in Figure 1.

In this use case, the system-of-interest is a single E-Walker. The E-Walker retrieves a PMU from the storage spacecraft and connects it to a defined connector port on the truss structure. The E-Walker has an elbow, shoulder and wrist joint – each powered by motors – providing 7-Degrees-of-Freedom (DOF) in total. It can walk across the spacecraft platform by latching one of its two End Effectors (EE) to one of the connector ports. An ontological representation of the E-Walker's architecture is shown in Figure 2.

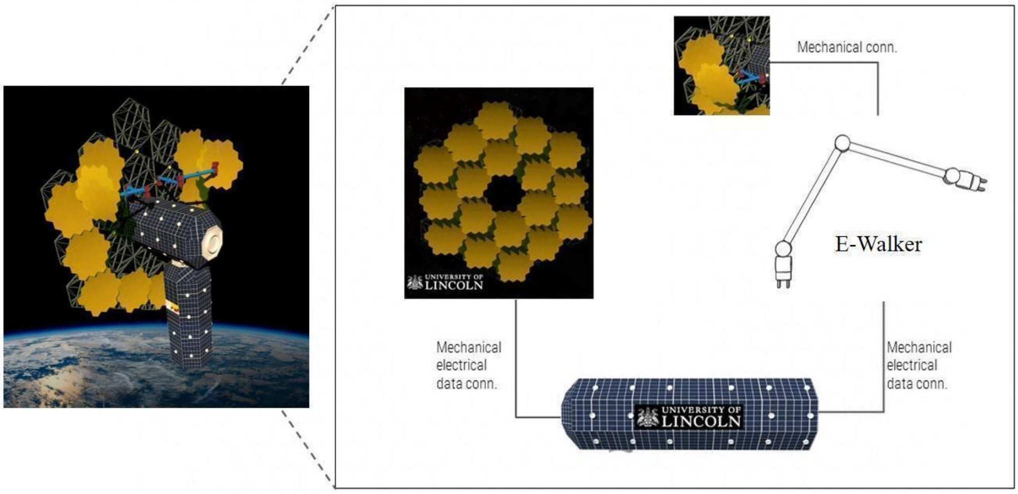

Figure 1. LAST Assembly Mission Scenario

System Requirements

The following system-level requirements have been identified for the specific use case:

R1. In all configurations, the E-Walker shall be capable of moving from the current connector port to the nearest connector port.

R2. The E-Walker shall have the following interfaces with the spacecraft platform:

- Mechanical; Power; Data

R3. The E-Walker Latching End Effector (LEE) shall maintain an accuracy of 5mm in all axes throughout its motion and during latching.

R4. The E-Walker power consumption shall not exceed 80% of the 'available power' supplied by the spacecraft platform.

ONTOLOGY DEVELOPMENT

The goal of this use case, therefore, is to capture the information regarding the systems engineering life cycle (e.g., requirements, mission scenario, system architecture, system behaviour, verification activities, information artefacts) in an RDF-based knowledge base, verify the requirements via simulation and provide traceability of the verification activities. The framework for this knowledge base will be provided by the SESO. Through automated reasoning with the knowledge base, it will be possible to verify the consistency of the different datasets and information artefacts, infer implicit knowledge and enable powerful querying. By integrating multiple domain-specific simulation and analysis tools with the knowledge base, it will be possible to simulate the system operations in a particular design scenario and formally verify system requirements. These functionalities will be implemented in the CloudSF platform, which is currently under active development [8].

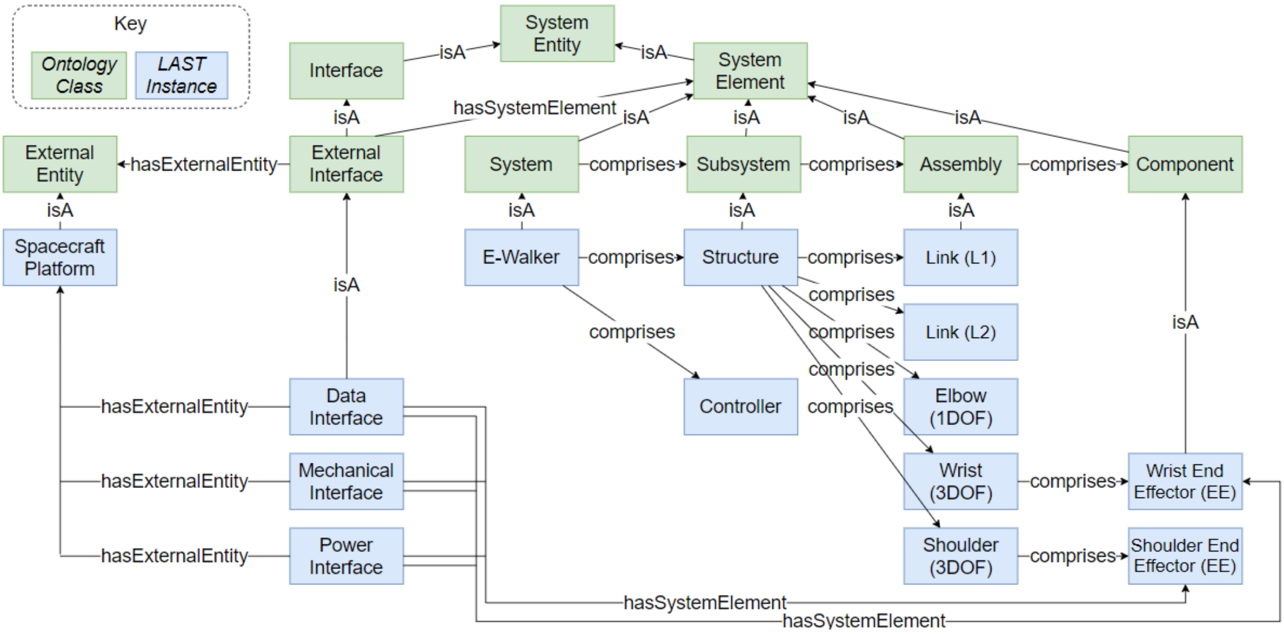

Figure 2. Top-Level E-Walker Architecture (note – some ‘isA’ properties are not shown for simplicity)

The methodology outlined in [10] is applied for the ontology development. This methodology includes five major steps:

1. Determine the domain and scope of the ontology,
2. Consider reusing existing ontologies,
3. Enumerate important terms in the ontology,
4. Define the classes and class properties (including the class hierarchy),
5. Create instances.

In line with *Step 1*, the domain and scope of the SESO has been determined, and the resulting high-level structure is presented in Figure 3. The possible reuse of existing ontologies (*Step 2*) and relevant standards have also been highlighted in Figure 3. Existing ontologies to be reused include the Information Artifact Ontology (IAO), based on the Basic Formal Ontology (BFO) [11], and the systems engineering ontology defined in [12]. The modular approach to the development of the SESO

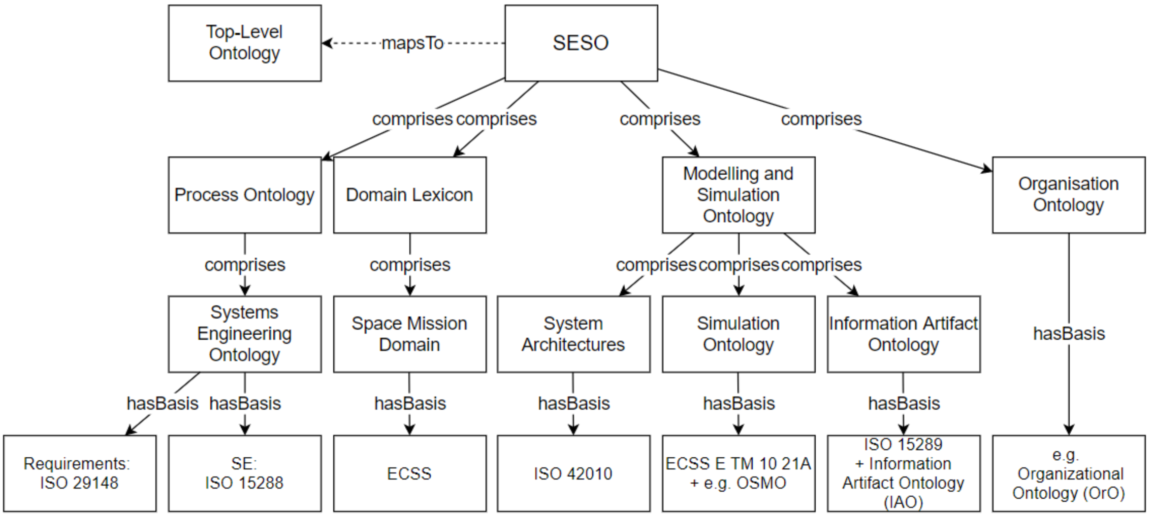

Figure 3. Structure of Semantic Systems Engineering Ontology (SESO)

encourages this kind of ontology reuse, and mapping to a top-level ontology such as the BFO ensures that the SESO remains consistent. In line with *Step 3*, important terms within each aspect of the ontology have been enumerated. In terms of the classes and class properties (*Step 4*), the SESO currently captures:

- Spacecraft logical and functional architecture,
- System operational scenario,
- Requirement types and satisfaction,
- SE Verification process (excerpt presented in Figure 4).

Future work will see the continued development of the SESO (*Step 4*) and the LAST knowledge base (*Step 5*), as more of the modules defined in Figure 3 are realised.

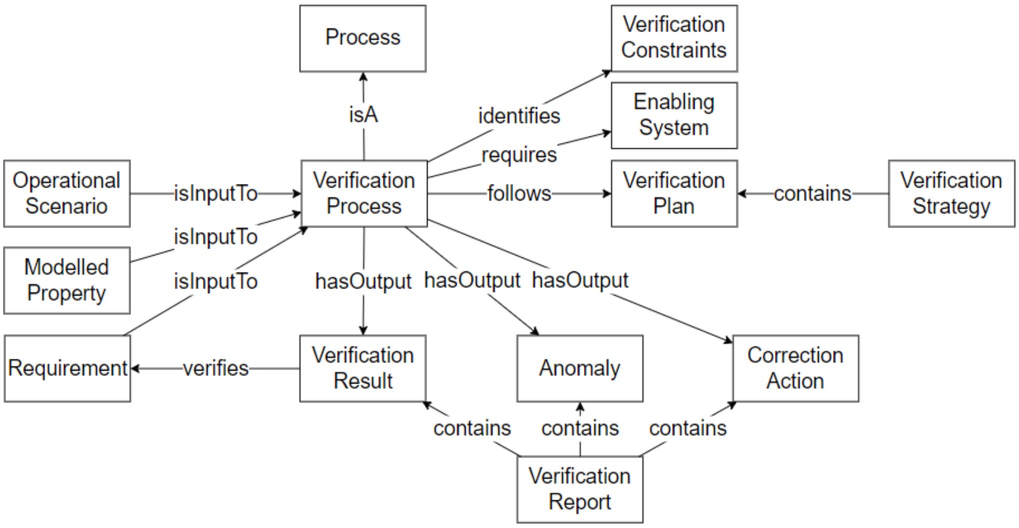

Figure 4. ‘Verification Process’ from Semantic Systems Engineering Ontology (SESO)

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