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CONNECTING SPACE SYSTEM REQUIREMENTS TO DESIGN MODELS WITH LARGE LANGUAGE MODELS

Abstract

The broader adoption of Model-Based Systems Engineering (MBSE) is driving a significant increase in the structured representation of space systems through languages like SysML or the Space Systems Ontology. However, natural language remains the primary representation modality for system requirement statements. This introduces the challenge of connecting elements embedded in the requirement's natural language with artifacts described in the model. Previous research has explored concept extraction from requirements and extracted facts from custom design knowledge databases related to a requirement. This paper fully generalizes these ideas to apply across different levels of design model availability. The spectrum spans three use cases. First, tracing the connection to design artifacts when given a spacecraft design model. Second, mapping natural language requirement fragments to abstract modeling elements from a custom space systems ontology or conceptual model. This essentially populates the ontology or conceptual model with elements from the requirements. Finally, when there is neither a conceptual model nor a specific design model, we describe the use case of connecting semantically similar fragments across requirements. In all cases, we rely on a recent and widely successful technology for natural language processing: pre-trained, transformer-based, large language models (LLMs) such as GPT-4. In the case of the model-based description of a design, we use the LLM-generated embeddings of the structured elements of a requirement to trace them onto the elements in the design description. We also explore different techniques relying on prompting for comparison. We apply a similar method to the third use case: finding closely related text fragments across the different requirements through embeddings. Our method differs from existing ones that evaluate similarity based on the complete requirement sentence. For the second use case, we test different prompting strategies to populate the structure predefined by a custom ontology or conceptual model. We train and benchmark our model with publicly available space system requirements datasets from past NASA and ESA missions, including the Herschel-Planck system requirement specification document and the JWST Observatory mission requirements document. This method will ultimately improve the consistency between design artifacts and the granular data given in natural language requirements, further enhancing the benefits of MBSE.