MODEL-BASED SYSTEMS ENGINEERING IN SPACE ROBOTICS: THE ADE EXPERIENCE

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ABSTRACT

Model-based systems engineering (MBSE) is the adopted practice for taming the increased complexity and heterogeneity of today's (systems-of-) systems under development. System modelling allows one to obtain abstract representations of the system by focusing only on the crucial aspects needed at the different development stages. These aspects can tackle for instance the design of the components performed independently by different engineering teams, the integrative design of the system in terms of communications, and the system design subject to formal verification and validation. Integrated in a model-driven development process, such as the waterfall model, and supported by many tools, MBSE provides a complete solution that aims to derive, possibly (semi-)automatically, implementations from high-level specifications. MBSE offers many benefits during the development phases: modularity and independent development of the different systems/components, reuse of components, compatibility with other systems/framework, and formally checked reliability and resilience.

In this paper, we present the MBSE formalisms, approach, and tools used in the H2020 Autonomous decision making in very long traverses (ADE) project (https://www.h2020-ade.eu/). The aim of the ADE project is to develop a demonstrator for a planetary rover capable of performing very long traverses (kilometres per sol), taking autonomously decisions required to progress, reducing risks, and seizing opportunities for data collection (opportunistic science). The rover will be able to perform high-level goals requested from ground, decompose these high-level goals into low-level activities, and perform these activities in real-time, while reacting to any hazardous situations and adapting the activities to the current conditions.

More specifically, the ADE design of the demonstrator involves the use of many models and technologies in order to achieve such crucial goals, some of them being beyond the state-of-the-art in space robotics. For autonomous decision taking, the ADE system integrates an on-board planner based on artificial intelligence (AI) techniques. This component uses the Problem Domain Definition Language (PDDL) for modelling the world and computational logic for reasoning and finding solutions. For opportunistic science, ADE integrates a scientific detector also based on state-of-the-art AI. This component uses trained neural network models that detect and classify scientific targets of interest. For long traverses, ADE integrates a rover guidance supported by a perception and localisation system that allows for autonomous path planning and hazard avoidance. Additionally, ADE uses a robotic arm for sample caching. These components use and implement control models to provide the basic functionalities of the robotic platform. For reacting to hazardous situations, ADE integrates fault detection, isolation, and recovery (FDIR) based on formal methods. This component uses Behavior, Interaction, and Priority (BIP) to formally model the system and check its correctness, at both at runtime and offline.

Finally, for the real-time execution of all these functionalities as well as creating the integrative design, ADE uses the TASTE tool. TASTE is an open source framework developed by ESA that enables the development of embedded, real-time systems based on MBSE. A TASTE system design is produced with standardized modelling languages (e.g., ASN.1 and AADL) describing different views of the system including views for

data types, components, as well as for the deployment. The tool-chain generates code for the target deployment platform (while enforcing real-time properties) and produces the system executable(s), among other features.

ADE develops other components, integrated in the considered demonstration scenario. A Ground Control Station enables the control of the system in different autonomy modes, as well as bookkeeping the results of the operations for further assessment. The navigation system is supported and checked by ground truth. Other offline assessments include the traversability of the terrain (soil), the simulation of the mission(s) and the replay of the operations performed by the robotic platform. Soil traversability is based on neural network models trained with data logged prior by the robotic platform. The simulation includes a model of the robotic platform in terms of kinematics, controlled by the ADE developed system. The aim is to evaluate and correct the functionalities of the demonstrator before field trials. The replay mode adds the assessment of the system performances from real logged data.

This paper will describe the models, approach, and tools used in ADE for the development of the planetary rover. We will present both the challenges encountered during the development, mainly related to the integration of many formalisms into a common design, and the approaches taken to address them. Finally, we will report on the experience of using different technologies and tools as well as the lessons learned

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