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AI4CE - Closing the design-operation-loop with AI: design, operate, learn, repeat

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Abstract

Modern system designs has to take a lot of requirements into account, but real-world experience is rarely given the opportunity to have a direct impact on new mission designs. AI for Concurrent Engineering (AI4CE) is a open source research project between TU Darmstadt and Parametry.ai, which examines the applicability of AI-based system generation to support the conceptual design phase. As one of several modules, OPS2Design will offer a formalised way to introduce constraints and requirements from the operations directly into the generation of new system designs, thereby closing the PLC loop.

Keywords: AI, system design, conceptual design, concurrent engineering, operational experience

1. Introduction

The design of a space mission is influenced by many factors, from the engineering details to finance, risk and scientific aspects. To accelerate the decision process and increase its efficiency, concurrent engineering (CE) has proven itself to be a valuable tool for agencies and industry alike. Research to further optimise the CE process identified modern AI tools of being able to further provide valuable advantages [1] [2] Past efforts to provide AI-based design expertise can be divided into two categories of approaches: Capable AI agents can offer additional design knowledge, by offering deeper insights about the experiences and decisions taken in previous design studies via text-based interfaces [1][2] (top-down) or by providing new, unbiased designs generated by AI-powered system generation tools (bottom-up). These two approaches both aim to support the CE teams in their pursue to develop conceptual space systems efficiently. They do differ, however, in the way they generate the supporting design knowledge - the first one extracting existing design wisdom to set it into a novel context, the latter one generating entirely new, design expertise just based on requirements and established engineering calculations. Additionally, they differ significantly in the scale of research conducted to date, with a clear focus on the top down method.
To generate space systems from the bottom up, the AI selects a set of suitable components out of a database of available components, based on a set of mission requirements. These requirements are provided in a format, which can be imported by the generating AI. This applies both to the requirements imposed on the system by the customer or the designing team, and to any requests that the operation may formulate for the basic design of the system.
The Artificial Intelligence for concurrent engineering (AI4CE) research project, as a collaboration between the TU Darmstadt and Parametry.ai, explores the use of AI-assisted system generation to support early design development. The core of the research is a platform to enable and support the development as well as validation of bottom up system generation
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2. Bottom-up AI-assisted System Development

Modern system development uses Model Based System Engineering (MBSE), which describes a procedural product development process, where all information from the first development phases of the system idea and in all later phases of the design, get collected in one single source of truth. It is a constant effort to unify all relevant aspects of the space industry into one model, which would facilitate the model exchange across agency or company borders. While this is mainly done for the early phases of the design phase, adding this approach to the whole Product Life Cycle (PLC) - including operations - can add additional possibilities to learn from it in succeeding design studies. The common, linear PLC of a spacecraft starts in Phase 0/A with its first concept studies, gets developed, refined, tested, launched and used during Phases B-E, until it gets finally deposed during Phase F. Automatically linking the experience about specific components and component combinations during operations (Phase E) back to the start of the mission design (Phase 0/A) - thereby closing the PLC loop, as shown in Fig.1 - will provide an extra level of knowledge to the designing team previously unknown.

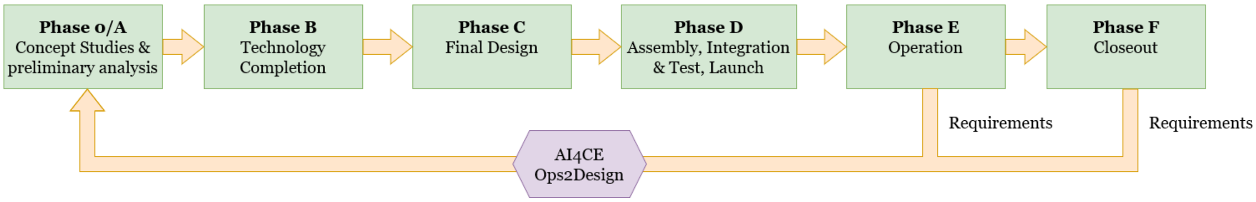

Figure 1 Each mission traverses through the same Product Life Cycle (PLC) [3]. AI4CE will close the PLC loop, by connecting Phase E/F of the current to Phase 0/A of the next mission, through a formalised way to describe requirements, which can be considered by the automated system generation.

The automated generation of conceptual designs can benefit from the operational experience in many ways and the advent of the digital twin concept made the implementation of experiences of operating previous spacecraft designs increasingly feasible. Mass production of satellite components caused, that satellite components get used in multiple missions. This means, that actual real world knowledge about operating these components can be gathered from the operation teams. Due to the long development and construction time of space systems, it is difficult to perceive a concrete impact of the design decisions. Therefore, it is extremely beneficial to get a direct influence of the operation during the creation of the design from operational experience. This is currently done by interviewing operation teams and including them into CE sessions. The design of a system is constraint by its requirements, which in AI4CE will be extended to not only comply to the mission objective, but also to cover the needs of an efficient operation. Modern space missions can chose from a variety of space components and have to rely on their own user experience and the data sheets of the vendors. Although it is not the dedicated subject of the preliminary design studies in Phase 0/A to fully design a system, an understanding of what real world components could be used to build the current version of the envisioned design will be of great value during the CE sessions.

3. Theory and calculation

The core of AI4CE is a digital platform for the design, implementation, test and validation of different system generation methods to support the CE process. The goal is to enable the design of AI-based system generators, which are tightly integrated into the CE workflow and require thereby a high level of integration with the designing engineers. The outlined operational workflow of a bottom-up system generation is visualised in Figure 2 The main focus is on the intensive provision of bottom-up procedures, through the systematic development of generation and validation tools. However, the platform is designed in a modular way, so that top-down procedures can also be taken into account by future studies. The bottom-up system generation process relies on the input of mission requirements together with databases of available components for the artificially generates mission designs. The input requirements for the system consist of the general technical requirements for a space system (environmental influences, remote operations), the specific requirements of the mission objectives (scientific instruments, commercial services, ...) and the requirements addressed from the experience of operational use. The team will update the mission requirement parameters according to their progressed design discussion, on which a novel concept can get generated by the AI system creator. To ensure a seamless integration into existing MBSE-centric CE activities and other MBSE tools, a dedicated MBSE integration module (DCC2Design) will be part of the AI4CE platform. Part of this module will be the functionality to formalise system requirements

4. Results

In order to bridge the gap from to operations to the design of a mission, multiple prerequisite research questions (RQ) are yet to be answered.

RQ1. Which metrics can be used to identify the relevant criteria of ongoing and historical space missions which have the most relevant impact on the next generation of spacecrafts?
To measure the impact of a space mission on the design of the next generation, first the relevant criteria have to be identified. While in classical mission design parameters like mass or power consumption are key design constraints, operations requires its own set of prerequisites. Expert interviews with operators of different domains will help identify their dedicated needs

RQ2. How can these requirements be formalised in a way, that they can be used for the Phase 0/A studies? Once the mission (design) critical parameters have been identified they can be fixed or monitored, but that still does not mean, that they can be usefully implemented during the mission design phase. The corresponding requirements have to be formalised in a schema, that can be implement during Phase 0/A studies.

RQ3. How can the influence be introduced to the design of a new mission? Once the necessary aspects of the space missions have been identified, formalised and collected, they still need to be implemented into the actual mission design. In regular mission designs this is handled as a set of requirements, which got defined by the missions customer before the concept study and evaluated with the engineering team after the study concluded. Therefore once the requirements are consistent with the fundamental requirements coming from the mission's initial customer, they can be implemented as regular requirements

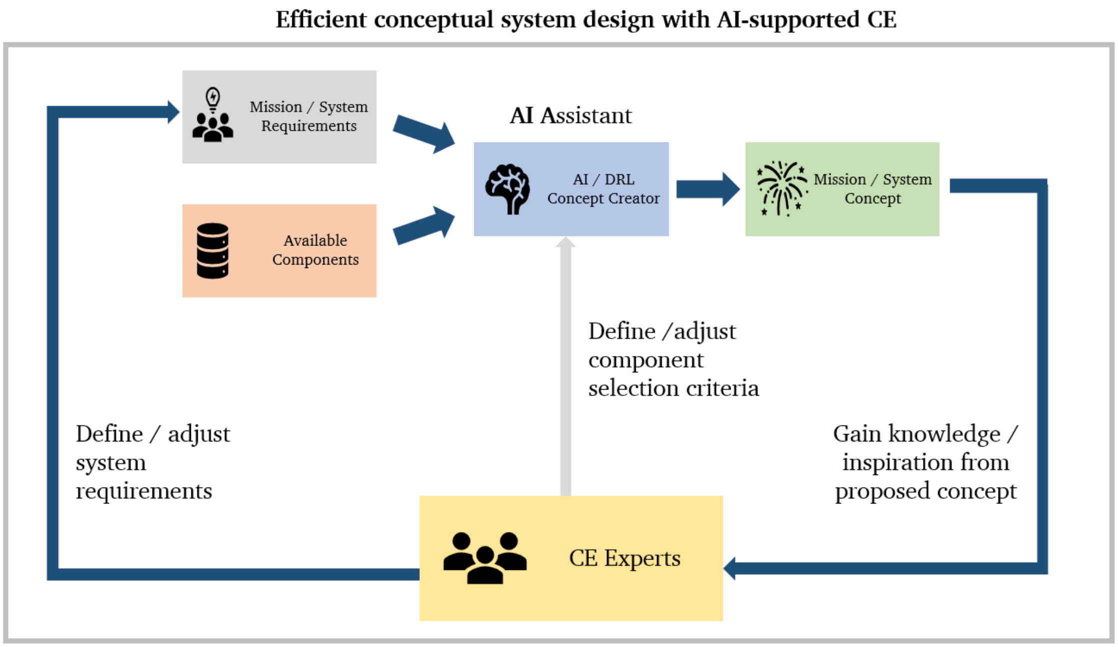

Figure 2 Overview of how a bottom up system concept creation workflow. The CE team receives information about the system's purpose and an MBSE model. Building on that, the team adjust the AI system's mission requirements. Together with additional information coming from the operations and a component database, a concept gets created. The CE experts will then review the created system and start a new iteration, until the final design is reached, which gets exported as an updated MBSE model.
The three models of the AI4CE project are highlighted as purple boxes.

5. Discussion

AI4CE is currently still in its early phase. A first prototype showcasing the feasibility of bottom-up system generation uses Deep Reinforcement Learning (DRL) to learn the best component combinations from the satsearch web shop. The generator is currently capable of generating real-world comparable simplified 1U CubeSat systems with support for solar panel, battery, camera, reaction wheel and transceiver module. The two other modules of AI4CE are the Deep Reinforcement Learning (DRL) Concept Creator (DCC) and OPS2Design, which functions as an integration module of component experience/knowledge during the actual operation phase. All 3 modules are marked purple in Figure 2. In addition to the general functionality of the bottom-up system generation process outlined above, the AI4CE platform will offer support tools and functionality to develop these bottom-up system generation tools. It is the selected goal to offer functionality to compare system generation methods. A GUI builder will help to outline the envisioned system architecture, which will be used by the DCC module to generate the system. After the system architecture has been configured, details about the be-wished AI method can be adjusted, before the system generation can be started. For validation of the generated system, a comparison module is envisioned to benchmark different system generation methods against each other. This will be achieved by special metrics to compare the outcome of numerous AI algorithms as well as static optimisation algorithms and designs created by human design teams. On behalf of the integration into a greater ecosystem of an industry-wide used tools for system design, AI4CE will also offer the functionality to export the generated design in other MBSE tools by relying on open system exchange formats, like explored by ESA's OSMOSE initiative.

6. Conclusions

Space operations and mission design are aspects of a spacecraft's PLC which mark the beginning and the end. Both procedures require dedicated, experienced personnel with special training and an exchange of operational experience to support the design process. AI4CE is a research project in cooperation between parametry.ai and the Technical University Darmstadt, which will provide a platform to build and validate AI-based engineering assistants to support CE studies. One focus of the research is on formalising design requirements so that an automated design tool can generate systems based on them, which means that design generation is also strongly based on requirements derived from operational experience. Although the development is still in its early steps, a first prototype offered promising results. Next steps in the development process will focus on the identification of relevant operational criteria that will influence the mission design and a schema for the formalisation of requirements. The project is completely open source and is licenced under the GPL3 license https://gitlab.com/ai4ce/ public-info

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