Extending System Engineering Methodology into the Era of Artificial Intelligence

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Abstract - **The world is on the footsteps of a time when the advances of technology supported by Artificial Intelligence (AI) will force all stakeholders to re-examine their traditional methods for designing and engineering of all future intelligent and autonomous systems. These systems would have the advantages of: Self-awareness, Self-control, Self-improvement through learning and could be Self-sufficient. We believe that AI and Autonomy shall go hand in hand in all future engineering applications. Modelling of applications, whether for Earth or Space, are lacking the capacity to model AI and autonomous systems lifecycle management. In this paper, we are defining the main guidelines that are needed to extend system modelling languages to cope with the future. This is while questioning, what a future engineering and planning lifecycles that support the migration from traditional systems to intelligent and autonomous ones, should look alike.**

Keywords- AI; Machine Learning; SysML; System Engineering; Advanced Technologies; System of Systems; Methodology.

I. INTRODUCTION

We live in an era when the increasing demand for more intelligent and autonomous technologies that can accommodate growing Terrestrial and Space applications from self-driven cars to space robotics, should influence the traditionally used engineering methodologies.

The state of the art in System Engineering is based on the capacity to model and define the system under design, that means, the capacity to accurately define the different systems' states using a well-structured modelling language and interfaces. Consequently, it has the capability to define system behaviour and influence actors. Albeit how a system model is qualified as of high fidelity, it cannot guarantee the designed system representation in a real world or cover its whole solution domain. There is a wide range of definitions for such intelligent autonomous applications. Some of them are more restrictive than others. However, the simplest one would have the capacity to emulate and simulate human intelligence operating a machine using learning, reasoning and interacting with a dynamic world environment.

That is why, system modelling languages and other techniques start adding more extensions to the languages to define space applications or provide more accuracy to problem resolution. Nevertheless, they are still lagging in their capacity to model accurately a dynamic system and better identify its behaviour and the dynamic world around it. This is the current state of our applications which we describe as intelligent, advanced and characterize them as autonomous.

In fact, such lagging is a result of the human trust and capability to validate and verify the presence of such requirements in our engineering documentation. We are not able to model, define, audit and verify requirements that should be in an intelligent autonomous system.

This paper discusses the principles to extend or add a new toolbox to model base system engineering principles. These principles are: self-awareness and discovery, self-control, self-improvement through learning and Machine to Machine connectivity and cyber security.

The paper is structured as follows. In Section II, we present the modelling guidelines that any AI or Autonomous (self-control) system design must comply with. Section III addresses a plan to handle and build on an organization knowledge and resources to address AI and Autonomy applications. Section IV presents our implementation. We conclude the paper with Section V where we present the conclusion and the future work to complete such research.

II. PRINCIPLES

Hereby, we are proposing the modelling guidelines that any AI or Autonomous (self-control) system design must comply with. Model Based System Engineering (MBSE) is the methodology of choice for most of the engineering designs. The Systems Modelling Language (SysML) was proposed by the Object Management Group (OMG) to address the challenges and needs in model-based system engineering [8]. SysML is a modelling language used to add powerful capacity to model a wide range of system engineering problems.

This section describes the extension proposal for SysML [5]. It presents the domain model of the extension and a proposal for the profile extending SysML for different AI & Autonomous systems modelling.

In this phase of our research, we based the extension definition to the following principles used in SysML: a domain model, a profile and a syntax [5].

A. Self-awareness

Living in a future engineering world application based on AI, there is a need to make sure that these applications have the capacity to understand and be aware of their environment [5].

In SysML, to be able to model self-awareness [7] for intelligent autonomous systems, we need a definition of awareness. Consequently, awareness would be the capacity

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to *recognize and understand the dynamic world model interactions with the system*.

B. Dynamic world modelling

In order to benefit from the self-awareness principle, the world model should also have the capacity to *dynamically model the world* where the engineering system would function. Dynamically modelling would provide the capacity of the first principle to be able and implement awareness.

In this paragraph we will not discuss the fidelity of the world model currently used or if it is dynamic or not. A world model, in our study, *must be able to discover and introduce new elements when necessary to the world it represents*.

C. System of Systems Modelling

To fulfil the dynamic world modelling in which a system would operate or function, this requires the capacity to model it from a System of Systems (SoS) view [2]. In fact, if we are modelling the design of a health system that allows vaccination in the current pandemic, among others, we must be able to model the socioeconomic reality of its world. In fact, such principle would allow the model *growth*. It also supports the understanding of the *dynamic behavior,* especially in complex systems. In this phase of research, we would start by the following inputs as an approach to define a dynamic System of Systems (SoS) world model [1] (paragraphs 2.2 and 2.3) [6]:

- Casual Loops;
- Stock and flow diagram;
- Equations;
- Equations in continuous time;
- Equations in discrete time; and
- Dynamic simulation results.

D. Machine-to-Machine Communication

Communication is an important aspect of our model. This principle, in addition to others mentioned, will support the understanding of the system model input and output. It will support the definition of required input to the model, how much the input is *trustworthy* and whether it *comes from a machine or not (discovery)*.

E. Self-improvement Through Learning

Machine Learning (ML) is the main new science of AI. The need to train the AI is becoming a major element in the success of any AI application design. Also, the fact that there is a Big Data repository that supports such ML approach. However, future designs, especially in the space industry, know a limit in space and time (RAM and CPU power). Consequently, *training and retraining* of the engineering systems is important. The state-of-the-art references multiple techniques, among which, the nearest neighbor algorithms that do not have a training phase and Naïve Bayes methods.

F. Autonomy (Self-control, and could be Self-sufficient)

Autonomy is another important principle whose modelling would be required. It would support the definition and the capacity of the system to *trust its output, control its inputs and outputs, request of support*. Support could come from another machine or from a human actor. A system might need maintenance training with new data down the road, and training is likely a continuous need.

G. Trust and Data Sets

In traditional systems design, especially in software (SW), configuration management is used to define a *data and system baseline*. However, we will need to handle *data and metadata configuration management*. This is new to the engineering methodology. Also, data need to be clean: complete and representative of the operation environment. Human-on-the-Loop actors might be required at early stages of the design to verify that data are relevant and behaviours are appropriate in response to the training [6].

H. Verification and Validation

There is no well agreed upon approach to test and this is Verify and Validate (V&V). Some researchers consider AI and ML systems have a black box approach to validate and verify the different systems requirements. There must be a capacity to model V&V of the system.

Consequently, this would contribute to increase the trust and confidence in the system. Also, it would allow the capability for test engineers to demonstrate the system compliance to requirements statements and requirements traceability.

III. Planning for AI and Autonomy

As stated, AI and autonomy are part of engineering applications future. Currently, most countries are building towards such future. The domain of AI and autonomy will experience strong world competition in the coming decades after the knowledge era. Governments started by establishing strategic plans in order to be ready and enter such augmented knowledge era. We believe that organizations should do the same. In fact, the burden in that age would fall on academia, industry, public and organizations addressing advanced technology more than any level of government.

Consequently, the state of the art including this paper proposed a plan to handle and build on an organization knowledge and resources to address AI and Autonomy applications. The section below presents a summary of the state of art as well as our own implementation plan.

The plan has to address the organization's needs, goals and objectives. It aims at identifying the objectives and priorities of adopting artificial intelligence and promoting autonomous operations in their respective industry, science or research. This is in addition to identifying opportunities and gaps that should be addressed, as well as outlining desired outcomes for this organization. Finally, this plan will describe the needed management and technical approaches and expected economic gains.

A. Autonomy and AI Strategy for the program

Define *what* are the AI and autonomy needs, objectives and goals and how they are linked to the organization's overall strategy.

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B. *Application Area Identification*

This section defines the potential ways in which autonomy and AI capabilities can be added to the organization's activities. This section will also assess the extent to which Autonomy and AI can be feasibly applied to meet a minimum set of goals. The section will conclude with the results of *why* Autonomy and AI can be used, rationale behind that conclusion and, if needed, a priority of implementation.

C. *Planning Section*

The plan has to outline when AI and autonomy shall be integrated at the different levels of products, operations, economic activities, etc. It will consider the different alternatives of building and buying Autonomy and AI solution to a specific problem as identified on Application Area Identification.

D. *Implementation Section*

In this section, the plan will explain how the Autonomy and AI will be best integrated within the program, including the possibility of the hardware being in space prior to the software being completed. It will also address how the ground segment can be designed to support data science and ongoing analysis results.

E. *Technology Aspects*

In this section, we will identify, what technology is required to achieve our Autonomy and AI priorities. Does the program have the right technology in place already? If not, what technology development do we need to put in place?

F. *What Is Next*

This section will detail the change management process and the key next steps. This section will be as a result of identifying a subsystem, a function or a technology that is targeted to be automated or a candidate to introduce AI.

IV. IMPLEMENTATION

Inspired by [4] we developed the following extension to adapt to our principles and extend the SYSML to accommodate AI and Autonomy applications.

Figure 1 shows the proposed domain model defined as a meta-model. This represents the syntax that can be used to describe the above mentioned principles.

Figure 2 offers a high-level view of the organization of the SysML profile. This SysML is proposed in order to extend SysML with constructs for AI and Autonomy principles' modeling. Similar to [4], the profile is organized into two top-level packages: the Ai-Autonomy Library and SysML. The first is an UML Model Library which defines datatypes and reusable concepts, while the other will contain the concepts of AI-autonomy data.

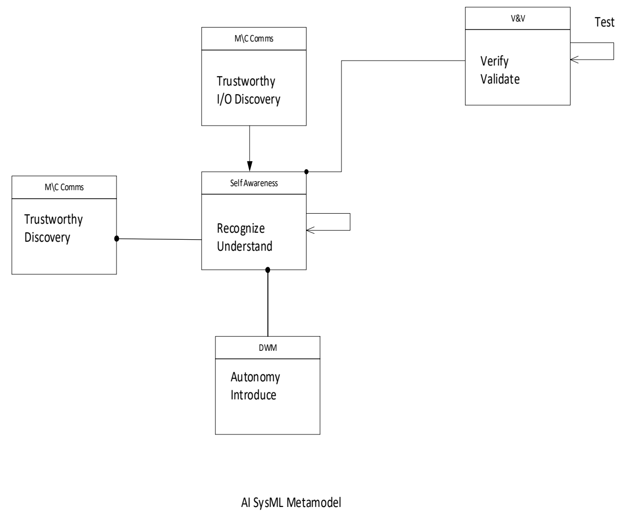

Figure 1. AI SysMl Metamodel.

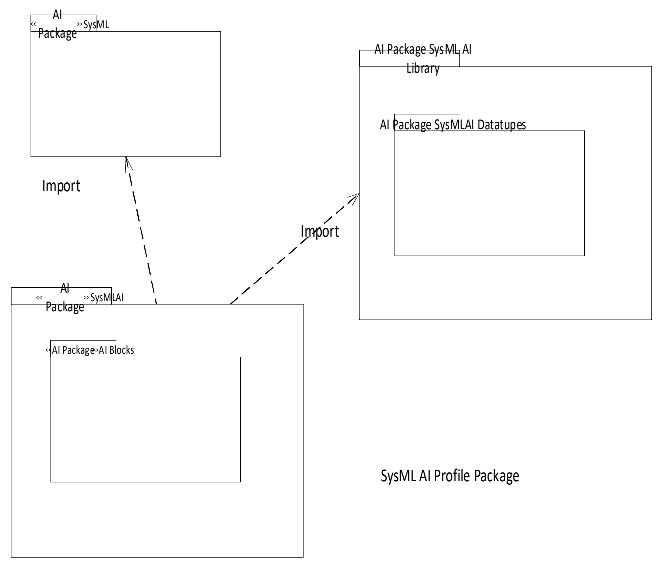

Figure 2. SysML AI Package

V. CONCLUSION AND FUTURE WORK

We started to implement the principles 2.1 to 2.4 as extension to SysML. There will be ongoing work to define the remaining ones.

We will also be studying additional principles such as Testing, Cyber Security due to the increased threat surface as a result of introducing AI-based systems. Also, the modelling of AI-based system standardization and certification.

We have also identified multiple challenges that we are working on as part of this research:

- Human role;

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    - Lack of human role to review and assume responsibility;
    - Human factors (HMI, etc.); and
    - User's acceptance.
- Learning and Big Data
    - Learning would require huge and continuous data, in fact, Self-improvement might require continuous source of huge amount of data.
- Self-awareness
    - Sensory input and lack of;
    - Knowledge base and the ability to reason about abstract concepts; and
    - Decision-making capability and legal social context.
- Computing power and the public trust in AI
- Would there be an AI standard or international global use rules?

This paper described an important aspect of our modeling of future AI and Autonomous applications. The traditional MBSE and systems engineering approaches and methodologies are well adapted to accommodate the advanced nature of those advanced technologies as represented by AI. The paper discussed multiple principles that MBSE tools based on SysML has to adopt in order to cope with the rapid AI based applications development. The paper presented in Section II a set of principles that would allow the current System Engineering approaches based on MBSE to model AI and autonomous systems. In fact, we extended the modelling of AI and autonomous systems to include SoS aspects. We provided a possible SysML extension based on the OMG work [8]. We are also investigating future work to improve our modelling approach.

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