AIDEAS

D3.1 – Industrial Equipment Design Suite v1

WP3 – BUILD: AIDEAS 4 Industrial Equipment Design

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RESPONSIBLE AUTHOR	Alexander Schulz		
CONTRIBUTIONS FROM	1 -CERTH, 4 - IKERLAN, 9 - IANUS, 10 - XLAB		
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ABSTRACT	This deliverable aims at presenting the features, the technical specifications, and the implementation status of toolkits to be developed in the Industrial Equipment Design Suite. Three toolkits are being developed in this suite: Machine Design Optimiser (MDO), Machine Synthetic Data Generator (MDG), the CAx Addon and Machine Passport (MP).		

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1.0	29-Mar-2024	Final Doc	Quality check and issue of final document	CERTH

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ABBREVIATIONS/ACRONYMS

AI	Artificial Intelligence
AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAx	Collective abbreviation for CAD, CAM and CAE
CFD	Computational Fluid Dynamics
CSS	Cascading Style Sheets
CORS	Cross-Origin Resource Sharing
DB	Database
DSS	Decision Support System
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
JSON	JavaScript Object Notation
MDG	Machine Synthetic Data Generator
MDO	Machine Design Optimiser
MP	Machine Passport
PDF	Portable Document Format
REST	Representational State Transfer
ROM	Reduced Order Model
STEP	Standard for the Exchange of Product Data
UI	User Interface
UX	User Experience
XAI	Explainable Artificial Intelligence

Executive summary

This deliverable aims at presenting the features, the technical specifications, and the implementation status of toolkits to be developed in the Industrial Equipment Design Suite. Three toolkits are being developed in this suite: Machine Design Optimiser (MDO), Machine Synthetic Data Generator (MDG), the CAx Addon and Machine Passport (MP).

The AIDEAS Industrial Equipment Design Suite provides AI-assisted optimisation modules that generate design proposals for the construction of industrial equipment. It represents the first step of the AIDEAS BUILD process for the AI supported industrial equipment life cycle, the DESIGN part, and aims at the development of AI-assisted optimization modules that generate design proposals for the construction of industrial equipment. The following specific objectives are addressed by the toolkits in this suite:

- Providing AI for Mechanisms, Structural and Control Components Optimum Design
- Providing AI for Data Synthesis and Quality Assurance by Bias-free Data
- Supporting AI Integration with CAD/CAM/CAE
- Supporting AI Management of Design Data with Machine Passport

In the following chapters, we first provide an overview of the solutions for each toolkit. Then we present all the features and functions of the solutions. Finally, we have presented the implementation status of the toolkits in terms of the current implementations (development status of the solutions in March 2024) and the next developments (the future development plan).

Document Structure

Each section of the document contains the information of one of the solutions, with a final section for conclusions, namely:

Section 1: Machine Design Optimiser

Section 2: Machine Synthetic Data Generator

Section 3: CAx Add-on

Section 4: Machine Passport

Section 5: Conclusion

1 Machine Design Optimiser

1.1 Overview

The AI^{MDO} solution uses AI-based algorithms to predict system behaviour and ensure that design parameters are accurately tuned to the specifications required for maximum efficiency and reliability. It enables designers to refine and evolve their designs based on AI-generated insights, reducing time to market and improving overall product quality.

1.2 Features

The main features and functionalities offered by the AIDEAS Machine Design Optimizer are the following:

- **Load Machine Configuration**: This component facilitates the reading of the inputs required to configure the machine (excel and executable files).
- **Configure Optimization:** This component allows defining the conditions in terms of ranges of acceptable parameter values.
- **Perform Optimization:** This component launches the optimization solver, given the selected model and the configuration of the ranges of values for the parameters.
- **Perform Evaluation:** This component extracts the results of the optimization and provides the best results.

The main problem that can be solved by using this solution is the early definition of the optimal set of design parameters that optimize the performance of the machine. With this approach, the user will be able to:

- Perform an optimization process with low computational cost and user-friendly interface.
- Analyse the sensitivity of the design parameters. Allowing to evaluate the influence of each parameter.

1.3 Technical specifications

The AI^{MDO} solution is fed with a trained simulation model that can predict the real behaviour of the machine to estimate the performance of the machine as a data-driven, model-based physical model. The solution for the implementation of the degradation model of the machine during its life has been developed based on previous work about wear simulation and expertise in the field and considering the state of the art from the literature. The solution has been enhanced and implemented in a more complex model (5 axis grinding machine) considering not only the joint but the behaviour of the whole machine in the simulation.

The optimisation process will be based on a sequential process where the results provided by the simulation model are used to generate a reduced order model (ROM) that will be used for the estimation of the optimal candidates. These candidates will be evaluated, and the ROM will be updated. The number of iterations can be defined by the user.

For deployment, docker is used since it is the most widely used containerisation solution and due to our expertise with it. Docker also makes it easy to deploy the packaged application into the runtime environment and is widely supported by deployment tools and technologies.

The technical backbone of the AI^{MDO} solution is built on Python to define important parameters for machine design with a lifecycle perspective. It uses libraries such as NumPy, Pandas, SciPy, Keras, PyTorch and TensorFlow in a Docker container environment. It has a React-based user interface, RESTful API integration for synchronous and asynchronous tasks, HTTP/HTTPS protocols for network security and uses MongoDB as the primary data repository.

1.4 Implementation status

1.4.1 Current implementation

Currently, the solution includes the following features:

- Definition of the physical based dynamic model of the use cases
- Creation or upload of the machine configuration file. The file can be saved too.
- Upload and visualize data from csv or excel files. Data can be visualized in both table and graphs.

1.4.2 Next developments

Future developments will include:

- Implementation of the IA based optimization process
- Implementation of the use case scenarios for the demonstration of the functionalities

2 Machine Synthetic Data Generator

2.1 Overview

The Machine Synthetic Data Generator (MDG) is a functional tool that enables the generation of simulation data for the CAD construction of a spiral distributor by receiving geometrical configuration data together with transfer models from trained design models and storing them in a data storage system. The AI^{MDG} is the optimisation and data generation module for the AI-based synthesis and training of data. Geometry data for production is generated by synthesising real and historical data from trained digital twins and CFD simulations by accessing the material library of common polymers.

2.2 Features

The optimisation process with AI^{MDG} involves two central features: the optimisation of the current die geometry and the design of a new die geometry for a spiral mandrel distributor.

For the optimisation of the current die geometry:

- MDG is used to generate simulation results of the current die state.
- MDG is used to evaluate manual changes to the mould before production.
- MDG and MDO are used to optimise the geometry of the die according to specific requirements such as maximum pressure, dwell time and homogeneous speed.

For the design of a new geometry:

- MDG is used to generate simulation data for different possible geometries.
- MDG and MDO are used for the automatic design and optimisation of a spiral distributor mould.

The result will be an optimised geometry of a fluid domain, which must be included in the real "steelwork" i.e. prototype construction of the die.

2.3 Technical specifications

The front-end components required to implement the given machine concepts and provide the operational boundary conditions were successfully created. These components were tested with dummy data sets and their general functionality and reliability ensured.

The AI^{MDG} tool processes a series of dictionaries stored in JSON files, each representing a single instance of the requested data set. These dictionaries automatically encapsulate the necessary parameters for simulation and optimisation tasks. The grammar of these dictionaries may vary depending on the specific MDG use case and the dimensional parameters selected for the dataset. Each data set is accompanied by BASE64-encoded data, which ensures efficient and secure data transfer between systems. The optimisation algorithm generates a prototype geometry of a fluid domain of a spiral distributor die in the backend system for download as a STEP file.

The technical backbone of the AI^{MDG} solution is built on Python, using libraries such as PyTorch, OpenCV and Scikit, with Docker containers for consistent deployment. It features a user-friendly

REACT interface, RESTful APIs for sync/async communication, secure HTTP/HTTPS networking, and uses MongoDB and Postgres databases for data management.

2.4 Implementation status

2.4.1 Current implementation

Currently, the solution includes the following features:

- Input interface for the parametric definition of the die
- Access point to the material data of frequently used polymers
- Input interface of boundary conditions and ranges of process and design parameters to generate the meta-model

Access to MDG is implemented in an internet browser and has no special hardware requirements. After login, the user can already use the following MDG functions:

- Definition of used material
- Definition of spiral distributor by setting parameters:
  - Component diameter [mm]
  - Headroom spiral [mm]
  - Headroom pre-distributor [mm]
  - Lead angle spiral [°]
  - Spiral profile width [mm]
  - Spiral profile depth [mm]
  - Spiral profile angle [°]
  - Barrel gap start width [mm]
  - Barrel gap end width [mm]
  - Bifurcation count [#]
  - Spiral rotation
- Prediction of relevant parameters such as velocity and residence time from the first meta-model without simulation.

2.4.2 Next developments

Future developments will include:

- Parameter Optimization: Define specific optimisation parameters such as maximum pressure or minimum residence time for the fluid domain of the spiral distributor. These parameters will guide the evolutionary algorithm in optimizing the design.
- Meta-Model Training: Ensure the Meta-Model of AI^{MDG} is adequately trained. This involves feeding it with sufficient data to accurately represent the behaviour of the fluid domain under different boundary conditions. Since hundreds of simulations are necessary for effective evolutionary AI, thorough training of the Meta-Model is crucial.
- Implementation of functional interfaces for the integration of CAx Addon and MDG: Design and implement interfaces that enable the CAx system to communicate directly with the MDG. This includes the transmission of commands to start simulations and the receipt of result files in STEP format.

- Meta-Model Integration: Integrate the Meta-Model of MDG into the MDO framework. This involves setting up communication between MDO and MDG to access the Meta-Model for evolutionary algorithms.
- Prediction of the optimal geometry and creation of a prototype: Download optimization results as STEP document.

3 CAx Add-on

3.1 Overview

AI^{CAx} is an add-on for Autodesk Fusion 3D CAD/CAM/CAE software which provides integration with AI-assisted optimization modules developed in AI^{MDO} and AI^{MDG}. Using this add-on designers can interact with the AIDEAS Machine Design Optimizer (MDO) / AIDEAS Machine Synthetic Data Generator (MDG) directly from Autodesk Fusion which shortens the design process by eliminating unnecessary steps. Designers no longer need to export the design from CAD software, import it to the MDO, run the simulation, and import optimised geometry back to CAD software but can accomplish all of this in the CAD software itself.

3.2 Features

The main features and functionalities offered by the CAx add-on are the following:

- Login to the MDO / MDG.
- Upload the model from Autodesk Fusion in STEP format to the MDO and create corresponding digital twin.
- List all existing digital twins stored in the MDO / MDG.
- Start simulation for the selected digital twin with provided parameters for single or multiple flows.
- List simulations that have been run for the selected digital twin, show parameters used to run the simulation and the simulation status.
- Download simulation results as a PDF document for successfully finished simulations.
- Retrieve optimized model from the MDO / MDG and open it in Autodesk Fusion or update current model.
- Notify the user when simulation completes.

The main purpose of this solution is to provide user friendly means of interaction with MDO / MDG directly from the CAD/CAM/CAE software.

3.3 Technical specifications

The core of AI^{CAx} add-on is implemented in Python programming language and uses Fusion Application Programming Interface to integrate with the Fusion. The user interface is implemented using web technologies (HTML, CSS, JavaScript, jQuery) which provide much richer user interface and user experience than standard Fusion UI components. HTML tables are implemented using the DataTables JavaScript library which is available under the MIT license.

The add-on interacts with AI^{MDO} / AI^{MDG} through the AI^{MDO} / AI^{MDG} HTTP API using asynchronous (AJAX) requests. The communication is secured using HTTP protocol and bearer token authentication scheme. The user must first sign in to the AI^{MDO} / AI^{MDG} application using username/password credentials. If successful, MDO / MDG returns the bearer token which is then used for all further communication with AI^{MDO} / AI^{MDG} and provided in the Authorization header. The AI^{MDO} / AI^{MDG} must return appropriate cross-origin resource sharing (CORS) headers to allow cross-origin AJAX requests.

3.4 Implementation status

3.4.1 Current implementation

Currently, the following features are implemented:

- Login to the MDO / MDG.
- Upload the model from Autodesk Fusion to the MDO / MDG and create a new digital twin.
- List all existing digital twins.
- Start simulation for the selected digital twin with provided simulation parameters.
- List simulations for selected digital twin and display simulation status.
- Download simulation results as PDF document.

3.4.2 Next developments

Future developments will include:

- Retrieve optimized model from the MDO / MDG and open it in Autodesk Fusion as a new version of the model or update current model.
- Notify the user when simulation completes.
- Ability to delete digital twins.
- Improve UI/UX design (user interface / user experience) and navigation

4 Machine Passport

4.1 Overview

The Design phase of the Machine Passport is a cornerstone component for managing manufacturing data across the product lifecycle. It simplifies the complex process of data handling, making it accessible to users without the need for deep technical knowledge. From ideation to drafting, this phase ensures that critical design data is securely stored, shared, and seamlessly integrated with manufacturing stages, enabling users to focus on innovation and optimization of industrial equipment, you can find more detailed information on D5.1 – Industrial Equipment Use Suite v1.

4.2 Features

The Machine Passport during the Design phase offers a suite of features tailored to enhance manufacturing processes:

- Data Centralization: Consolidates design data from various sources, providing a single source of truth.
- Seamless Integration: Connects with computer-aided design systems to facilitate real-time data exchange.
- User-Centric Design: Simplifies data access and manipulation, tailored for ease of use without sacrificing functionality.
- Design Optimization: Utilizes collected data to suggest improvements for the optimal construction of machinery.
- Problem-Solving: Addresses issues such as data silos, miscommunication during design handoffs, and iterative design inefficiencies.

4.3 Technical specifications

Technically, the Design phase leverages state-of-the-art technologies to ensure robust and secure data management:

1. Data Protocols & Standards: Adopts industry-standard data exchange protocols ensuring compatibility and security.
2. Multi-Source Data Management: Uses advanced database solutions to handle diverse data formats and sources.
3. Explainable AI (xAI): Implements xAI algorithms to make the decision-making process transparent and understandable.

The Machine Passport components are developed in JAVA, using Spring Boot among other libraries, and requires Docker, MongoDB and Postgres databases, with no user interface, but equipped with RESTful APIs over HTTP/HTTPS. Setup involves importing the project into a JAVA IDE, making sure Postgresql and MongoDB are running, and running the main.java file.

4.4 Implementation status

4.4.1 Current implementation

As of March 2024, the Design phase of the Machine Passport has successfully integrated with multiple data sources and established a user-friendly interface for accessing design data. Initial xAI algorithms have been implemented to assist with design optimization.

4.4.2 Next developments

Moving forward, the focus will be on:

1. Enhancing the XAI capabilities to provide deeper insights into the design decision-making process.
2. Expanding the range of compatible computer-aided design systems for broader industry application using other solutions produced knowledge.
3. Increasing automation in data processing to streamline design workflows.
4. Further refining the user interface to ensure intuitive navigation and data manipulation.
5. Implementing additional security protocols to safeguard sensitive design data.

5 Conclusion

The AIDEAS Industrial Equipment Design Suite work package represents a systematic advancement in AI-assisted optimisation modules for industrial equipment design. With a dedicated focus on enhancing these modules, the suite comprises three essential toolkits: the AIDEAS Machine Design Optimizer (MDO), AIDEAS Machine Synthetic Data Generator (MDG), and AIDEAS CAx Addon (CAx). Recently, the addition of the AIDEAS Machine Passport in the Design phase has further augmented the suite's capabilities, providing a comprehensive solution for managing manufacturing data throughout the product lifecycle.

Machine Design Optimizer: The AI^{MDO} toolkit serves as the foundation for designers seeking optimal design parameters in multi-physical systems. By allowing low-cost, user-friendly optimization processes, it empowers users to analyse design parameter sensitivity, facilitating early definition of optimal sets. The current implementation covers dynamic model definition, machine configuration, and data visualization, with future focusing on AI-based optimization processes.

Machine Synthetic Data Generator: AI^{MDG} assumes a central role in the AI-based synthesis and training of data, generating geometry data for production. The tool's features include die geometry optimisation, definition of boundary conditions, and material data access. Future developments encompass parameter optimisation, meta-model training, and seamless integration with CAx Addon, solidifying MDG's role in shaping efficient design workflows.

CAx Addon: AI^{CAx}, the CAx Addon seamlessly integrates with Autodesk Fusion, streamlining the design process and enhancing user-friendliness. Current features allow users to log in, upload models, initiate simulations, and manage digital twins. Future developments focus on retrieving optimised models, user notifications, and the ability to delete digital twins.

Machine Passport (Design Phase): Introducing the Machine Passport in the Design phase signifies a substantial advancement in managing manufacturing data. With features like data centralisation, seamless integration with CAD systems, and user-centric design, it addresses challenges such as data silos and design inefficiencies. The current implementation integrates with multiple data sources, providing a user-friendly interface. Future developments target enhanced xAI capabilities, expanded compatibility, increased automation, refined user interfaces, and heightened security protocols.

Future Prospects: As the suite progresses, outlined developments underscore a commitment to continuous improvement, expanded functionalities, and heightened security measures. This strategic roadmap positions the suite to adapt to evolving industry needs, maintaining its leadership in AI-assisted industrial equipment design.

The current status of the solutions shows that the suite is in line with the project schedule. As of now, no major deviations about the solutions are known or expected. It can therefore be assumed that the suite can be completed.

6 References

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