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Human-Centric Assembly Cell Validation Supported by Digital Human Simulation

André RUECKERT [a,1], Marc NIEMANN [b,2], Eric KAM [c,3]

[a,b,c] *ESI Software Germany GmbH Liebknechtstrasse 33 70565 Stuttgart, Germany*

Abstract. Digital transformation toward optimized production process planning, highlights new challenges for assembly process planning departments as we move toward fully virtual engineering processes. ESI Software Germany GmbH (ESI) wants to introduce an important project outcome generated by the MOSIM (Modular Simulation of Human Motions, www.mosim.eu) framework – an open framework for efficient, interactive simulation and analysis of realistic human motion of manual assembly-worker sequences for industrial applications. The ESI - IC.IDO solution is one of the proposed industry solutions aiming to re-use the project outcome to extend existing IC.IDO process validation capabilities and enhance human-centric assembly environment validations completed in entirely virtual try-outs. Currently, the impact of assembly process plans on the people, who produce, use, and maintain a proposed new product, is often left unquantified until late in the product lifecycle. In some cases, identification of issues comes too late to mitigate through product design change or improved assembly methods for the shop floor. The goal of MOSIM is to increase comprehension of, and provide capability to shift, manufacturing engineering paradigms through the integrated evaluation of products in processes with the people who build, use, and maintain those products throughout their lifecycle. There are no solutions on the market yet, which comprehensively address human-centric engineering factors during assembly process planning that includes on-board realistic human simulation capabilities. ESI intends to use the MOSIM project results to improve manual, human-performed, manufacturing assembly procedure validations and generate dynamic simulations of human-centric motion in production environments. This will lead to a major reduction of time and effort needed to conduct shopfloor worker assembly simulations compared to current industrial practice – compared to approaches using digital mock-up (DMU) solutions for worker simulation studies. Identifying ergonomic opportunities during the assembly process to improve worker productivity, safety, and training. MOSIM has enormous potential to influence numerous stages of production.

Keywords. Human Centric, Process Planning, Assembly Validation, Digital Human Simulation, MOSIM

[1] andre.rueckert@esi-group.com
[2] marc.niemann@esi-group.com
[3] eric.kam@esi-group.com

1. Introduction

Every day, disruptive companies emerge to challenge the status quo with reduced structural costs, more nimble methods, and simpler approaches. Dynamic enterprises devise clever strategies leveraging new technologies and new mentalities to overrun the slower, historical processes of larger corporations. Existing companies must align to the new market conditions or will loose market share.
To cut costs and hopefully reduce lead times, Program Managers can not afford to design iteratively using trial and error with physical prototype designs, validation, and manufacturing teams must be involved from the start to reach a common understanding of the design without constructing a prototype. They must experience the product in context to understand the product before it exists. This is as true for manufacturing and assembly on the factory floor as it is for the engineering design of the product. Even with today's automation, the assembly of vehicles and other manufactured products still requires significant manual work. Much about the production planning process can be improved, as workers' tasks are typically not visualized in 3D but described in text. Additionally, validation for these tasks occurs on hardware prototypes. Simulation can make this experience more effective but generating a process simulation of human activities is time-consuming and requires tools for experts. As production of cars, trucks, and other mobility solutions becomes increasingly complex and competitive, the need to maximize efficiency is paramount. At the same time, manufacturing companies look for new ways to assure safe and ergonomic workplaces. Reliance on physical testing and optimisation not only hinders productivity and inflates costs, but often leaves manufacturers lacking confidence in their operational efficiency.

Within the European economy, digital modelling activities and particularly the simulation of human motion, have emerged during the last decades across various domains from mobility industries over pedestrian simulation to the gaming and entertainment industries. Even though differing in their respective scope, the ability to realistically predict real-world observations has shown to be a key technology to remain competitive.

For mechanical and mechatronic components, this trend is already covered by various research projects [1],[2] related to smart factories. In contrast, the generation of a rich repertoire of realistic human motions in complex and possibly highly collision afflicted environments are not sufficiently addressed by commercial tools, yet. Moreover, complex process workflows with an exhaustive number of possible manual task sequences can only be partly addressed today, since process variants must be modelled directly. As manual modelling is additional effort, the potential cost reduction is significant. In contrast to a deterministic simulation that might compute that a motion path is plausible for the installation of a component, a human operator will observe that, without non plausible human powers, they might not be able to see the workspace clearly enough to complete the task. Computer animations to illustrate a proposed process can take hours to prepare, requiring specialized skills to manipulate a digital human model like puppeteering and could still fall short of proving the validity of the procedure. Working in a Virtual Reality (VR)-enabled Virtual Build [3], an engineer can, within seconds, evaluate, perform, and optimize an assembly sequence and tooling manipulation intuitively, just like they would in a pilot production facility.

First-person exploration [Figure 1] only gets you so far because the circumstances are unique to the individual. Production will likely be distributed to different locales and performed by the local population, for localized product variants, in a unique production environment. Adding the ability to record and playback object animations, extends that singular experience over the potential a range of localizations in real-time. Capturing the assembly experience of other individuals in VR not only reaches the value of physical pilot assembly lines, it can reflect plausible production conditions that would take years of production to observe, mitigate, improve, and resolve.

Figure 1. First person exploration within IC.IDO

Sequences coupled with advance anthropometric digital human models, allows virtual build users to apply their first-person actions to "manikins" reflecting any number of regions, gender, and proportions. It becomes easy to experience, in the virtual environment, building a new product, and directly arrive at objective analytics for a diverse range of potential workers. Thereby it is possible, for example, to learn that, a 95% European male who performed an assembly action with ease could assign that same action to a 5% Asian female manikin and discover that she would find the same task uncomfortable or even unfeasible.

With the use of IC.IDO (I See.I Do [4]) ESI [5] offers a solution for Human-Centric Assembly Process Validation capabilities. This immersive virtual workspace enables multi-disciplinary collaborative evaluations, discussions, and resolutions to the challenges that new products and processes bring to the factory of the future [Figure 2]. It allows individuals or teams, together or from remote sites, to experience and interact with digital designs, so that engineering teams can identify necessary improvements and engineer corrections before design starts on tooling for the manufacturing plants.

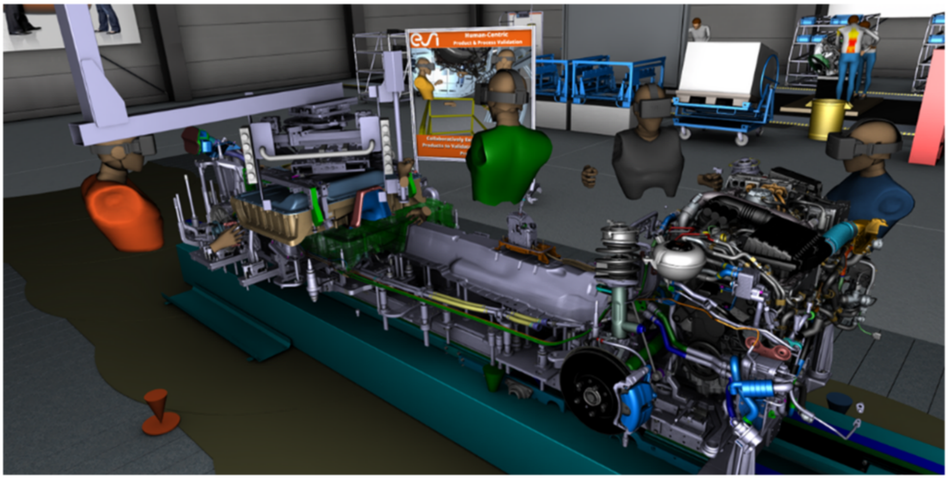

Figure 2. Collaborative Workspace / Assembly Process Workflow

The ESI IC.IDO industrial solution helps product and manufacturing engineering managers address challenges brought by shorter product life cycles, globalization and new technology trends, to better manage the risk of missed production targets (delivery, cost, quality, safety); through real-time, rich-context, virtual (VR enabled) validation of human-centric production processes, facilitating early identification of issues and improvements while reducing reliance on traditional off-line simulation, costly physical trials, or limited expert opinions. The goal is to provide a further strengthened platform for Human Centric Experiential Discovery & Validation, providing a rich virtual twin of the assembly environment, thus enabling efficient and reliable decision making by the key stakeholders. No matter if they are involved in the manufacturing engineering, assembly ramp-up, or production operation processes, a Collaborative Virtual Workspace expands digital continuity with upstream and downstream workflows for efficient integration within the customer processes.

2. ITEA3 driven MOSIM project

ESI is part of an ITEA 3 [6] driven project consortium called MOSIM [7] (**Mo**dular **Si**mulation of Human **M**otions). It is an open modular framework for efficient and interactive simulation and analysis of realistic human motions for professional applications. The ESI IC.IDO solution is one of the proposed target industry solutions who wants to use the project outcome for later industrial use mainly to enhance the current capabilities within the human centric assembly validation area.

The impact of present engineering practices on the people who produce, use, and maintain products is often left unquantified until late in the product lifecycle; in some cases, too late to address in the immediate product design or even the next generation. The idea of MOSIM need to increase comprehension of current engineering and manufacturing paradigm the integration of products and processes on the people who build, use, and maintain products throughout their lifecycle. There is no holistic solution on the market (state of current knowledge) which takes care of human factors during assembly including realistic/plausible human simulation [8] capabilities on-board. ESI's intention is to use these projects' results for improving human centric manufacturing/manual assembly evaluations.

MOSIM [Figure 3] also transfers the idea of co-simulating models from different simulation environments to the field of human simulation by means of introducing the Motion Model Units (MMU) [9]. To achieve the mentioned goals, three main approaches, each incorporating various technical contributions which clearly go beyond the current state of technology, will be explored within MOSIM.

MOSIM

End-to-end Digital Integration based on Modular Simulation of Natural Human Motions

Figure 3. MOSIM project focus

The above-mentioned drawbacks and problems are addressed in MOSIM by using innovative algorithms for autonomous decision-making, integrated simulation software and a modular framework, encapsulating motion generation algorithms. The overall goal is to create and introduce IT components, which allow automated natural human motion synthesis using a library of specialized motion generation approaches.

3. MOSIM innovations

One of the three major innovations outcomes of the MOSIM consortium is a library of MMUs, which will be distributed to third party integrators via the project website (www.mosim.eu) and next plan will be introduction of a marketplace or app store. Each of these components incorporates a specialized motion generation approach and offers standardized interfaces like the Functional Mock-up Interface standard. A MMU is considered to be a black box unit, modelling a specific type of behavior (e.g., "pick up") regardless of the underlying motion generation algorithms - which is not accessible to the integrator. The latter ensures a protection of the provider's intellectual property and thus introduces a business model for small and medium companies possessing detailed know-how of simulating motion within their respective use-case. Moreover, the novel interface structure enables each MMU component, to further consist of a set of other fine-grained MMUs - i.e. the unit "pick up" can comprise "reach", "grasp", "gaze" and "relax" - hence allowing aggregation layers of complex motions [Figure 4]. Each of the novel units might be parametrized using standardized interfaces in order to influence the resulting motion, which finally is mapped on the Digital Human Model (DHM). To underline the applicability of this concept, first, MOSIM defines a set of atomic MMUs using a use-case-independent classification of human motion - for instance the lowest aggregation level of methods-time measurement (e.g., "reach", "grasp", "position"). Second, heterogeneous motion generation approaches, both data-driven and analytical, will be explored and subsequently encapsulated within the respective MMU. The most distinctive advantage of this concept is the possibility to merge various specialized motion generation approaches into one common framework, which reinforces the benefits and compensates the drawbacks of the respective algorithms, ultimately resulting in holistic and use-case-independent solutions. Moreover, a library of MMUs significantly reduces the complexity and efforts for simulation vendors since a realistic motion can be easily generated by means of executing a series of MMUs instead of explicitly modelling and implementing each task.

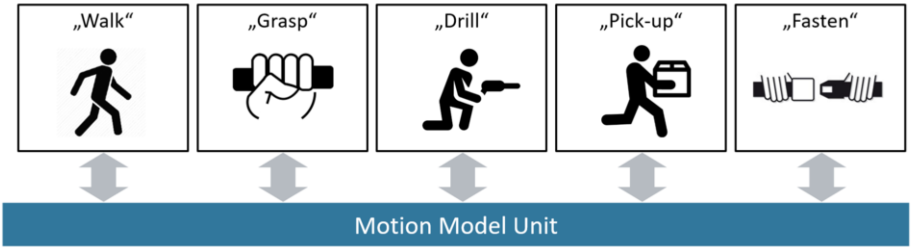

Figure 4. Examples of Motion Model Units

The second major novelty is embodied by models and algorithms enabling autonomous reasoning and automatic generation of MMU sequences based on generic workflow models. As discussed, the proposed MMU concept is mainly distinguished by the idea of discretizing motions into modular units. Thus, a specific high-level task (e.g., fastening of a nut using a screwdriver) can be easily simulated by means of executing a set of MMUs in an adequate order. Moreover, process variants can also be simulated using a slightly different combination of these discrete units. To automatically generate sequences for high-level tasks, MOSIM will introduce generic workflow models, which describe all possible MMU combinations of this task. These models will be generated and maintained both, automatically using field data and manually using knowledge about processes. Note that these models can be further encapsulated within yet another MMU, which strongly supports the idea of layered complexity handling. Based on these models, artificial-intelligence-based reasoning approaches are investigated to automatically derive in real time an optimal sequence of discrete MMUs based on context information, i.e., the three-dimensional scene and the state of the DHM. The advantage of this innovation cluster lays in the significant reduction of the overall complexity for the simulation or animation vendor, since all possible process variants can be automatically derived, while requiring only neglectable manual efforts. Moreover, the process of deriving a plausible sequence from the exhaustive number of variants has no longer to be carried out manually, resulting in more plausible/better results and in real-time decision making.

Having developed the library of MMUs and determined a logically plausible sequence, the concept and implementation of the modular simulation framework, generating continuous and realistic human motions from this sequence, represents the third innovation cluster. In general, this topic can be divided into two main threads of research: First, the development of generic constraint models enabling a smooth transition between two consecutive discrete motion units. This step also includes approaches to determine to what extent and how different MMUs can be parallelized. Based on these concepts, MOSIM will furthermore develop so-called co-simulators (see FMI standard [10]), which generate continuous and natural motions. For this reason, MOSIM will explore sequencing algorithms and models to execute the list of MMUs in an optimal and possibly parallel manner in real time. Finally, MOSIM will introduce approaches to map the generated behavior (e.g., the parallel execution of gaze, grasp and walk) to the digital human model, ultimately resulting in a realistic motion [Figure 5]. All these aspects enable automatic generation of continuous movements based on arbitrary sequences during runtime, which complements the above-mentioned benefits of reducing the complexity and effort for the simulation vendor, while increasing the level of realism.

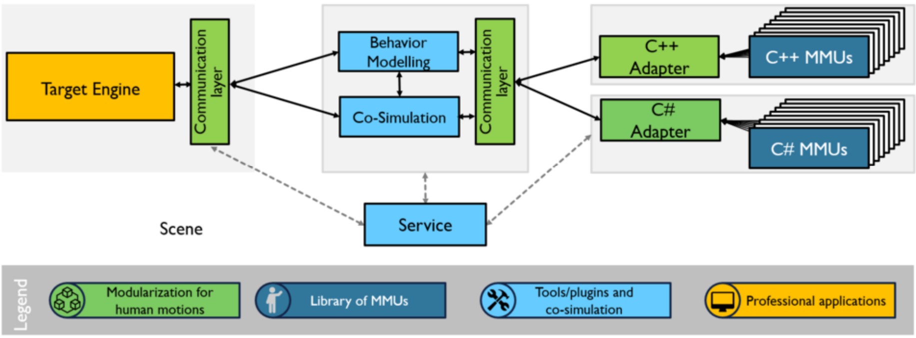

Figure 5. MOSIM general concept

The main ideas behind MOSIM are:

- Concept and Implementation of an extensive **library** consisting of **MMUs** encapsulating various human motions regardless of the respective use-case.
- Development of tailored approaches, enabling **autonomous generation** of plausible **MMU sequences** and context-dependent decision-making using recent AI methods.
- Unifying both approaches, a **co-simulator** will be implemented, generating natural and continuous human motions by **sequencing** and **executing** the obtained set of **MMUs** using generic transition models.

The main expected outcomes for the MOSIM outcomes for ESI IC.IDO are:

- Extension of IC.IDO assembly process validation module
- Validation of assembly sequence plans from workers perspective (people, tools, resources)
- Integration of MOSIM platform into IC.IDO “target engine” to simulate human centric assembly processes (automated) [Figure 6]
- Use of RAMSIS kernel (by Human Solutions GmbH [12]) to make use of MMUs in IC.IDO: Ergonomic analysis (e.g., RULA [13]])

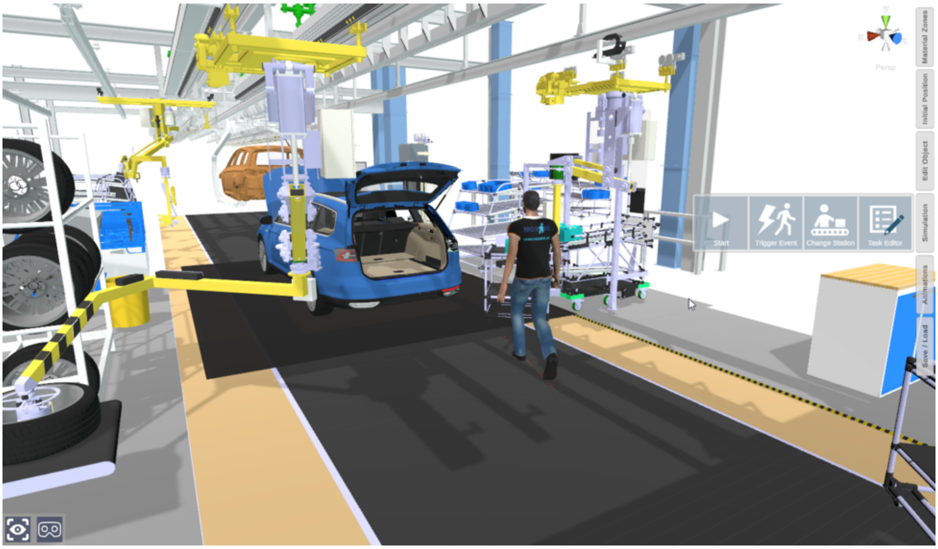

Figure 6. Virtual TryOut Environment using MOSIM concept (based on UNITY[11])

Industrial focus on MOSIM project outcome

The generation of a rich repertoire of realistic human motions in complex and possibly obstructed environments is not sufficiently addressed by commercial tools. Complex process workflows with extensive manual task sequences can only be partly addressed today since procedural variants must be modelled by hand. As manual modelling is high additional effort, the cost reduction potential is significant. MOSIM aims to develop and implement a generic concept inspired by the Functional Mock-up Interface (FMI) standard, to automatically simulate broad variety of realistic human motions, implemented through new methods and software solutions [Figure 7].

IC.IDO solution is, as already mentioned, one of the industry solutions proposed to re-use the project outcome, extending existing IC.IDO process validation capabilities and enhance human-centric production environment validations completed in entirely virtual try-outs. Currently, the impact of assembly process plans on the people, who produce, use, and maintain a proposed new product, is too often unquantified until late in the product lifecycle. In some cases, identification of issues comes too late to resolve through product design change or improved assembly methods for the shop floor.

Figure 7. Virtual TryOut Environment using MOSIM concept within UNITY

A huge paradigm shift is expected and implications for automotive production:

- From the viewpoint of an assembly station, nearly each **product** can be considered **unique**
- Associated **assembly tasks** may vary within each cycle
- Rising **complexity** and **efforts** for production planning departments
- Simultaneously, **changed paradigms** are leading to a **decreasing prediction** quality of planning methods

Also a huge reduction of invested time compared to current industrial practise (based on DMU related human task simulation).

The goal is to further strengthen the platform for Human Centric Experiential discovery & validation, providing a rich virtual twin of the assembly environment, thus enabling efficient and reliable decision making by the key stakeholders. The focus of MOSIM is also to increase comprehension of, and provide capability to shift, manufacturing engineering paradigms through the integrated evaluation of products in processes with the people who build, use, and maintain those products throughout their lifecycle. With no solutions currently on the market that comprehensively address human-centric engineering factors including on-board realistic human simulation during assembly process planning . ESI intends to use the MOSIM project results to improve validation of manual, human-performed, manufacturing assembly procedures and generate dynamic simulations of human-centric motion in production environments [Figure 8]. The MOSIM outcome will lead to a major reduction of time and effort needed to conduct shopfloor worker assembly simulations compared to current industrial practice – compared to approaches using digital mock-up (DMU) solutions for worker simulation studies. Identifying ergonomic opportunities during the assembly process improves worker productivity, safety, skill transfer and retention. MOSIM has enormous potential to influence numerous stages of production.

Figure 8. Paradigm shift for simulating human motions in future

This dynamic simulation of humans in production – based on predefined motion units with a standardized interface - can simulate assembly worker tasks in minutes rather than weeks [14]. Companies can improve production planning, increase worker productivity and safety, and reduce risks and costs. The main benefit for the workers is that digital human modelling helps to identify work-related risks in scenarios that are difficult to assess with traditional approaches. The approach helps by eliminating working conditions that negatively impact safety and worker well-being.

4. Outlook on MOSIM project results

ESI wants to propel the MOSIM concept [15] from an industrial perspective to relevant enterprises in automotive, aerospace or heavy industries, for example, to define an industry standard within the consortium. From an industry perspective, the MOSIM outcomes will generate added value for already existing human centric process validation capabilities of ESI IC.IDO [Figure 9], through deep focus on validating operator jobs in final assembly lines within a virtual tryout environment.

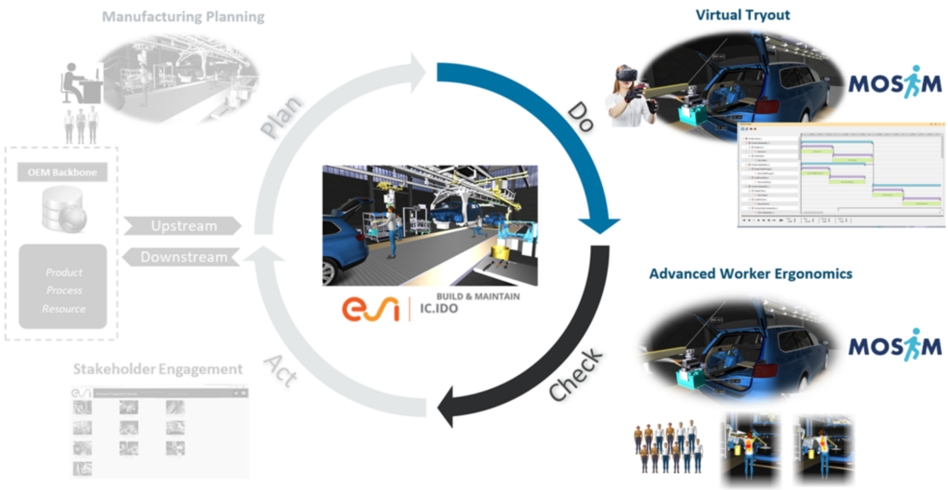

Figure 9. Concept of integrating the MOSIM concept into IC.IDO

Continued reliance on existing process simulation tools would generate a huge manual effort in creating this very massive simulation environment to check workers jobs in detail. ESI wants to implement a holistic virtual try-out environment to check workers JTBD (job to be done) directly from the workers perspective much earlier in the process by using the MOSIM output for the automatically generated worker animation sequences derived from existing planning output. Generating an autonomous process getting necessary process/geometry into the virtual try-out system with a minimum time and effort on preparation and the use of high-fidelity scenarios. ESI IC.IDO also wants to ensure in using MOSIM to generate a common solution which can support planning & manufacturing departments also in case of unexpected environmental issues (e.g., pandemic) to be able to have a flexible virtual try-out environment to manage changes on the assembly line or the implementation of new regulations and no need for being onsite.

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