MOSIM

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

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Work package 1
Use case definition and prerequisites

Deliverable 1.2
State of the Art

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Executive Summary

The content described in this document is part of MOSIM output for deliverable D1.2 "*State of the art analysis*" from WPI. The aim of this document is;

- To collect related research works and implemented practical applications in the field of digital human motion modelling. In this objective, existing theories and practical implementations in either lab or industrial level are collected using data collection tools.
- To cluster papers according to the respective topics and motion modelling taxonomies. Here, strong keywords are identified and used to group literatures and application scenarios according to their relevance to the topic.
- To conceptualize and analyze the state of the art according to MOSIM work packages
- To summarize and conclude the literature analysis

The document is structured as follows:

Section 1 Introduction: This section describes the overview of the document, the scope and the methodology.

Section 2 Overview of work packages: This section provides the relationship of MOSIM work packages and the state of the art analysis. Additionally, the proposed MOSIM framework is presented.

Section 3 State of the art analysis: In this section, literature analysis is presented in five categories. These categories are created by considering theoretical and practical relevance of digital motion modelling.

Section 4 Summary and Conclusions: This section briefly summarize the overall document and concludes the state of the art.

The primary conclusion includes the following:

- There are different approaches for the requirement of human movement simulation. These are useful to analyze; design and arrange workplaces, human factors and the wellbeing of individuals, and to easily animate human motion.
- Human motion simulation is considered from two perspectives. There are digital human models, i.e. DHM is represented by two approaches for a specific domain. There are two dimensional motion planning and full body motion generation and motion synthesis approaches, i.e. these are data driven or example-based motion synthesis approaches that rely strongly on reference and example datasets, which are predominantly realized by means of motion capture. They are characterized by features such as motion blending, motion graphs, statistical models and artificial intelligence.
- Exchange of simulation models and functional mock-up interface format is one of the desired targets by many researchers. The standard FMI tools include xml-files compiled in C-code. Currently, there exists no interoperable motion generation algorithm format. It is solely possible to exchange instances of the generated motion itself, which, however, cannot be directly manipulated. For exchanging motions between different simulation tools, two of the most frequently utilized formats are Biovision Hierarchy (bvh) and Filmbox (fbx).
- A unified language that entertains behavior theory and simulation techniques is necessary to integrate multi-domain systems into interchangeable simulation engines. These approach includes multi environment CAD models integration, control algorithms, graphic computation and simulation, scene definition, behavior characterization, sensor data, system model and in some cases multibody models.

Contents

1 Introduction

1.1 Overview

The aim of the deliverable is to analyze the state of the art for simulating realistic and modular human movements in different applications for defined scopes such as ergonomics, musculoskeletal, biomechanical simulation and animation systems. However, in order to overcome the challenge of data collection and handling approaches, systematic approaches are used to search, filter, archive, and cluster information according to their scope. For this matter, marketing hubs, project databases such as ITEA, European projects and National funding agencies, research databases such as link springer, Elsevier, science direct, ACM libraries, IEEE and others are considered. The management of the literature is handled by Zotero which is an open source tool.

Depending on the main keywords and human motion modelling taxonomies, five main sections are presented, as it is described on table of contents. These categories include:

- Simulation approaches for human movements
- Exchange formats for simulation algorithms
- Simulation of human motion Automated reasoning and behavior modelling
- Sequencing, co-simulation and constraint models

Based on the relevance of literature against five categories, literature clustering, data extraction and interpretation strategies are applied. This analysis is conducted based on data collection methods and tools which are capable to process text, image, hyperlinks, videos, and audios.

Furthermore, the overview of MOSIM work packages in relation to the state of the art are presented. The reasoning technique (WP4), MMU framework (WP2), MMU library (WP3) and co-simulation (WP5) are structured within the respective topics and sections. Thereby, the proposed MOSIM approach is presented. Finally, this document provides a summary and conclusion of the state of the art analysis.

1.2 Scope

The features of modular based natural human motion synthesis, modelling and simulation are covered in this document. Systematic literature analysis is conducted to derive the state of the art analysis. Literature is analyzed into five categories as it is presented in section 3. Governing digital human motion taxonomies such as behavior modelling, motion characterization, model constraint, sequencing and co-simulations are applied to cluster the literatures for implicit analysis. In general, the scope of this document is limited to behavior, motion and co-simulation approaches in different domains of applications.

1.3 Methodology

The methodology employed to conduct a literature analysis has two approaches. These approaches include theoretical knowledge about modular motion modelling and the illustration of motion modelling and simulation with practical use cases. In both approaches, relevant taxonomies such as motion synthesis, analysis, generation, blending, ergonomics, co-simulation, game animation, mock-up units, behavior modelling, process sequence, and workflow optimizations are identified to cluster papers. In general, for this document, 84 research papers and 25 websites are filtered and considered as potential reference to conduct the state of the art analysis particularly in this project.

A data collection tool such as searching and filtering tools are used to extract information from different sources such as Google, Google scholar, Springer link, IEEE portal, ACM library and YouTube. Content information from texts, numbers, images, audios and videos is extracted and sorted according to the defined taxonomies. This include the set of methodological procedures to identify, record, understand, interpret and transmit information or data among the different work packages of the MOSIM project.

2 Overview of work packages

The project MOSIM is structured in eight work packages (WP). This deliverable document is part of the first work package (WP 1) which is responsible to define the goal and scope of the project for all subsequent tasks. Based on these results, the requirements and the concept for both, the MMI pre-standard and the modular simulation framework will be investigated within WP 2. Next, the technical work packages 3 to 5 will introduce a generic tool-set for generating the respective demonstrators. Figure 1 illustrates the relation between these three clusters. WP 3 will develop a use-case independent MMU library, which can be used within a wide range of domains. Using this database, WP 4 will present approaches to automatically generate MMU sequences based on a high-level task - in this case "drill hole in wall" - on a purely logical level. Being executed sequentially, this list of motion units would logically fulfill the desired task, however, would lack of realism due to discontinuities (e.g. the end and start pose of two consecutive MMUs might be different). Moreover, humans tend to perform multiple tasks in parallel (e.g. reach and walking), which is also not covered by this list. WP 5 will solve these problems by exploring sequencing algorithms and transition models, ultimately leading to a continuous, plausible and realistic motion (refer figure 1). WP 6 will build multiple demonstrators (one for each use case) using this generic framework.

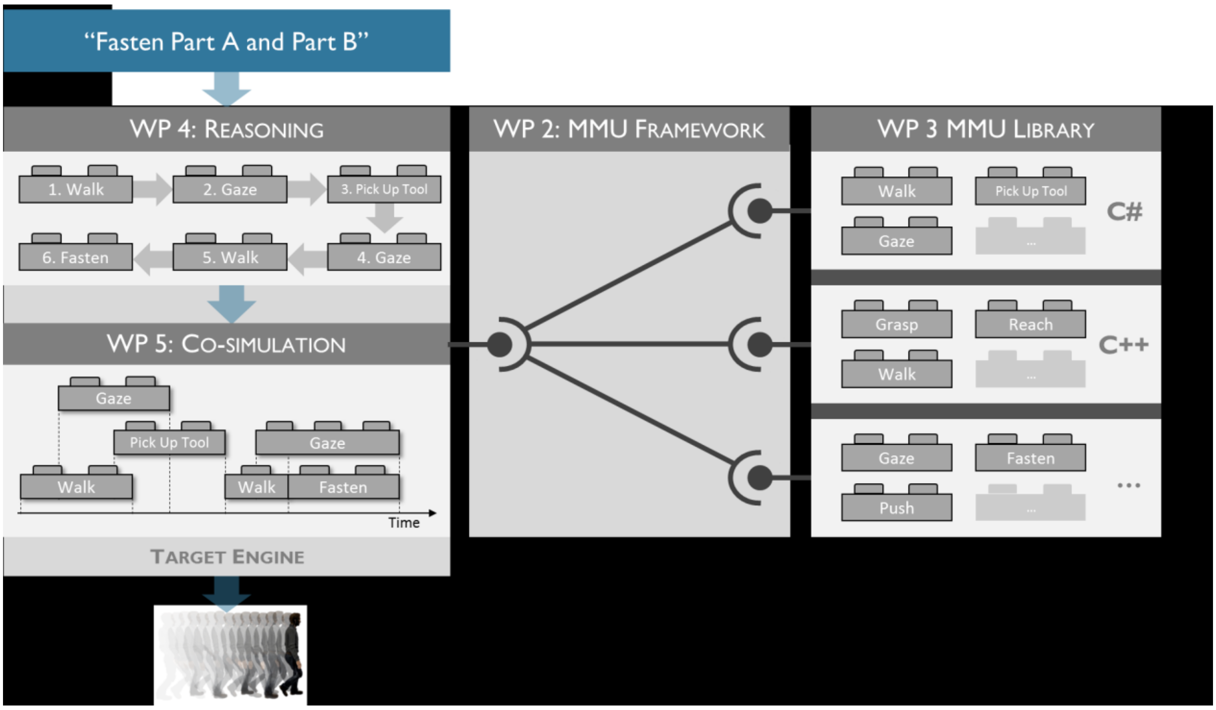

Fig. 1: A Proposed MOSIM approach overview

3 State of the art analysis

3.1 Simulation approaches for human movements (WP1)

During the last decades, an exhaustive number of tools for simulating human movements have been developed for various scopes of application ranging from ergonomics-, over musculoskeletal- and biomechanical-simulation to animation purposes. Even though offering a great potential to virtually plan, design and analyze a wide range of aspects related to the human body, the predominant proportion of solutions being available both, on the market and in academia solely focuses on their specific use-case. In particular, the approaches can be classified according to their respective scope of application:

3.1.1 Ergonomics

This important domain focuses on the analysis, design and arrangement of workplaces, products and systems with regard to the abilities and limitations of the people using them. Depending on the respective use-case, the tools utilize DHMs comprising of varying level of details, in combination with specialized motion generation approaches. However, the simulation of complex and extensive workflows induces uneconomical manual efforts, since postures and processes have to be predominantly modeled by hand. A representative overview of associated tools and their digital human model comprises of following solutions: DELMIA [1], Dynamicus Alaska [2], Ramsis [3], IMMA [4], Siemens Jack / Jill [5], Santos [6], 3DSSPP [7] and Sammie [8]. Moreover, the virtual human simulation provided by Fraunhofer IAO [9] and Smart Virtual Worker from TU Chemnitz [10] are prominent tools for workplace and ergonomic assessment.

Fig. 2: Digital simulation of natural human motions (image: MOSIM official webpage [11])

3.1.2 Musculoskeletal and biomechanical modelling

This cluster of simulation approaches, being related to ergonomics, utilizes high-detailed DHMs including a fine-grained representation of musculoskeletal- or organ-system. These tools precisely model and analyze motions of the human body, however, at the expense of the real-time capability. Wide-spread tools within this group are AnyBody [12], LifeModeler [13] and OpenSim [14].

3.1.3 Workflow optimization

Besides analyzing human factors and the wellbeing of individuals, others present approaches and tools, focusing on the optimization of workflows - such as the simulation of an assembly workplace including the order of assembly tasks or the position of racks (see IPO.log [15]). In general, these approaches are holistically covering overall-workflows on a rather abstract level, however, neglecting important factors (e.g. muscle forces, cognitive load or the reachability of points) to a large extent due to the use of algorithms, only roughly simulating human motion (see EMA [16]).

3.1.4 Animation Systems

Another cluster, which received significant attention during the last years, is the group of character animation systems. These tools provide gaming-related platforms including various tools (e.g. retargeting of DHMs), to easily animate human motion. Even though the approaches achieve outstanding results in terms of naturalness in game-related environments, difficult movements in highly collision-afflicted setting (e.g. surgery rooms, a truck or passenger car) can only be scarcely simulated. Important tools within this cluster are: SmartBody [17], Unity Mecanim [18], DI-Guy [19], Unreal Skeletal Mesh Animation System [20], CryEngine Character Animation System [21], Rocketbox / Havok Engine [22], Maya bodybuilder [23], Daz Studio [24] and POSER [25].

Fig. 3: Character animation toward predefined tasks [26].

3.1.5 Gaming

In contrast to the above mentioned systems, which can either be purchased or are publically available, the gaming industry possesses a broad spectrum of proprietary DHMs being optimized to the scope of respective game genre (e.g. sports, shooter or strategy). In general, this domain is tightly linked to the above mentioned animation systems and therefore present similar technical characteristics.

Even though obtaining excellent results within their respective domain, the vast majority of these specialized approaches fail when being transferred to another context - i.e. when applying a gaming related motion (e.g. FIFA) for analyzing individual muscle forces. Moreover, neither a holistic simulation framework nor an approach investigation the modularization of motion generation algorithms is currently existent.

3.2 Exchange Formats for Simulation Algorithms (WP2)

3.2.1 Exchange of simulation models via the Functional Mock-up Interface (FMI) format

FMI is a standard that supports exchange of dynamic models as well as its co-simulation while being tool independent. This standard, based on a combination of xml-files and compiled C-code, was developed between 2008 and 2011 within the ITEA 2 project Modelisar [55]. An instance of an FMI component is called a Functional Mock-up Unit (FMU). A zip archive containing several files describing a model is basically such a FMU. Inside this zip archive an xml file containing information about parameters, variables and further information about the model is included. The functions included in the archive itself, e.g. model equations, can be stored either as source code or in binary form as dynamic link libraries. When storing functional information in binary form, it is possible to include these compiled binaries for different platforms. With the FMI standard it is possible to perform a simulation of different FMUs, containing appropriate solvers, where only the simulation results of the FMUs are exchanged after defined time steps. This approach is called FMI for co-simulation [56,57]. To organize the whole simulation and to enable data exchange between FMUs, a co-simulation master is required. The simulation can also be distributed to different computers. Even though being a widespread in various domains, the FMI standard is currently not available for human motions.

3.2.2 Exchange formats for generated motion

As currently no interoperable motion generation algorithm format exists, it is solely possible to exchange instances of the generated motion itself, which, however, cannot be directly manipulated. For exchanging motions between different simulation tools, two of the most frequently utilized formats are Biovision Hierarchy (bvh) and Filmbox (fbx). Whereas bvh is mainly used for storing animations of humanoid models, the proprietary fbx format can be also utilized to store additional scene information. Even though both formats are widely used and several large motion capture library exists, nevertheless they are only capable of storing pre-generated motions (e.g. recorded by a motion capture system). Thus, it is not possible to integrate motion generation algorithms within the files itself. As a consequence, the motions can be only partially adjusted afterwards, instead of utilizing a full motion generation approach. Summarizing the state of the art in the context of exchange formats for motions it can be stated, that no solution is available yet for storing arbitrary motion generation methods.

3.3 Human motion simulation (WP3)

3.3.1 Digital human models

In order to actuate and steer the movements of the DHM within the simulation software, literature and market are presenting various approaches to generate motion. Human motion synthesis can be principally addressed with varying approaches and levels-of-detail, depending on the requirements of the specific domains. In general, the motion generation approaches can be subdivided into two dimensional motion planning and full body motion generation.

Two Dimensional Motion Planning

Various research has been carried out in the field of two-dimensional motion planning, in which humans are solely modeled as a two dimensional representation. Generally, these algorithms aim at generating an optimal and collision-free path between a start and end point. These approaches can be generally divided into global and local motion planners, whereby the former is used for applications in which all obstacles are known a priori [27]. According to Gasparetto et al. [28] this group can be further subdivided into roadmap techniques (i.e. Lozano and Perez [29]), cell decomposition (i.e. Hart et al. [30] and Nash et al. [31]) and algorithms using potential fields [28] . Other approaches use rapidly exploring random trees [32], genetic algorithms[33], interpolation methods [34] or neural networks as presented by Glasius et al. [35]. In contrast, reactive local motion planners are modeling dynamic behavior while taking into account the desired characteristics and restrictions of the system to be simulated (i.e. human locomotor system). Various approaches have been used for this purpose, ranging from steering behaviors [36] over randomized models [37] to velocity obstacle algorithms [38,38,39]. Apart from the exclusive use of one of the presented categories, others combine global and local motion planners to a hybrid system, thus fusing both advantages [27].

Full Body Motion Generation

Whereas two dimensional motion generation approaches mainly focus on collision free motion planning in two dimensional spaces, the group of full body motion synthesis aims at modelling all movements of an articulated avatar, which may comprise several joints and dimensions. A recent overview of motion synthesis approaches is given by Guo et al. [40]. The full body motion generation approaches can be generally divided into analytical and data driven approaches. Analytical motion synthesis approaches try to generate realistic motions based on intrinsic mathematical models or physics-based approaches [41]. Most of the time in this cluster, inverse-kinematics-based approaches [42] are utilized to manipulate motions of articulated avatars.

a. b.

Fig. 4: Full body modeling and motion synthesis: a) DHM skeleton (image: DFKI) b) Full skeleton reach motion [43]

3.3.2 Motion synthesis approaches

In contrast to the aforementioned analytical approaches, data driven or example-based motion synthesis approaches rely strongly on reference and example datasets, which are predominantly realized by means of motion capture. These approaches can be further subdivided into different categories.

Motion Blending

One widely spread category which is utilized in diverse animation systems is motion blending and interpolation. Motion blending is not a pure data-driven technology, it nevertheless strongly relies on the underlying datasets. In general, motion blending approaches generate novel motions which fulfill certain constraints by interpolating/extrapolating given motions, with specified interpolation weights. According to Feng et al. [44] these blending approaches can be clustered into K-Nearest Neighbour (KNN), Barycentric, Radial Basis Function (RBF) and Inverse Blending. Furthermore, geostatistical motion blending [45] received significant attention.

Motion Graphs

Beside motion blending, the concept of motion graphs [46] also received significant attention. The core idea of the motion graph approach, is to build a directed graph based on an automatic segmentation of example data, whereas individual samples of the motion data are considered as edges of this graph. The obtained graphs can be traversed in order to generate realistic motion and to consider constraints. This approach can achieve realistic motions and works well for small to medium motion capture data amounts, however it does not scale well in terms of computational performance.

Statistical Models

Probabilistic approaches targeting human posture are recently receiving wide attention in various domains [47,48]. Generally, these statistical models contain an infinite number of motion variants thus enabling the generation of a rich repertoire of motions based on a finite number of input datasets. In contrast to deterministic approaches simulating human motion, statistical models are based on the assumption that the human locomotor system comprises an infinite number of styles and postures. Moreover, it is assumed that different executions of one motion primitive show an intrinsic relationship, which may be approximated using statistical models [47]. Based on these assumptions, various approaches have been presented ranging from Hidden Markov Models [49], to Gaussian Process Dynamical Models [50]. Furthermore, multiple works [48,51] combine deterministic methods with statistical models. Min and Chai[47] present a data driven approach, probabilistically modeling fully-articulated human motion based on a large number of motion capture recordings, hence synthesizing continuous style variant motions. Du et al. [52] adapted the approach to assembly workshop scenarios. Manns et al. [53] point out the influence of quality to the effectiveness of the approach and investigate motion capture effort for creating models that cover common shop-floor motions. Results suggest considerable requirements regarding motion quality and quantity for realistic full body motion data synthesis of shop floor data.

Artificial Intelligence

In addition to the above mentioned approaches, the motion generation of full body motions is also realized by means of artificial intelligence. In this field recently deep learning-based motion synthesis [26] raised significant attention. Moreover, approaches like proposed by Holden et al. [54] allow a novel way of automatically generating a large repertoire of motions without utilizing manual blending and annotation approaches - also applicable in constrained environments.

3.4 Automated reasoning and behavior modelling (WP4)

Various approaches have been investigated to characterize human activity and the interrelated motion behavior. The most commonly identified human behaviors such as human gestures, human actions and human activities are characterized by complex motion features involving reasoning and behavior modelling.

3.4.1 Automated reasoning

Automated reasoning is the automatic identification of logical consequences of assumptions about a defined problem, expressed in a formal language, with a proof calculus. A reasoning framework is composed of an inference system which defines a search space of possible states and a proof procedure respectively a search plan [58]. The most widely used inferencing method is deductive reasoning or rather the inference from general to specific facts. Other techniques to move from premises to conclusions are inductive, and abductive inference rules. Automated Reasoning has its roots in studies, from the late 19th and early 20th century, about a universal language, Hilbert called it metamathematics, to describe the foundations of mathematics with which it can be proven [59]. Then in 1956, Newell et al. [60] published the first automated reasoning program. The major applications of Automated Reasoning beside of proving mathematical theorems, are verification, optimization and synthesis. Thus, many logics, which can be divided into classical or non-classical logics, are developed for different purposes, like model checking, decision making, learning, planning, or probabilistic reasoning [58].

3.4.2 Behavior modeling

Another important area in Artificial Intelligence and a well-established paradigm in the field of virtual human simulation are agent technologies [61–64]. Agents are the key technology for controlling the behavior of autonomous systems. Wooldridge et al. [65] defines an agent as an autonomous software entity, having sensors and actuators to perceive and interact with its environment to reach goals. An established architecture to model agents is the Belief Desire Intention (BDI) [66] paradigm. BDI agents have beliefs, intentions, desires and a plan library. Plans are executed in a Hierarchical Task Network (HTN) [67] based manner, depending on intentions and beliefs, to reach desires respectively long term goals of an agent. Because of usability purposes, BDI agents are often modeled with graphical languages like UML [68] or BPMN [69]. Other behavior languages for agents, mostly used in the game industry, are Finite State Machines (FSM) [70], its modular enhancement Hierarchical Finite State Machines (HFSM) [71], or Behavior Trees (BT) [72]. In all these approaches, behaviors need to be predefined and can only adapt automatically to environmental changes in a limited manner.

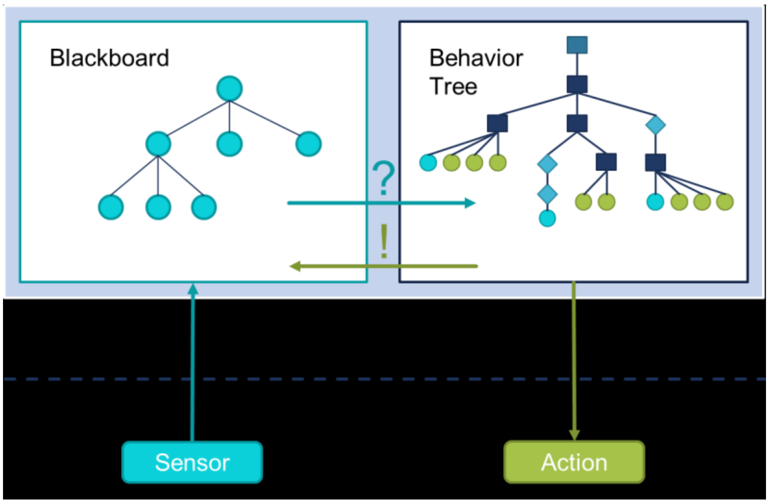

Fig. 5: A concept development of behavior modeling and control

The decision making process of a software agent respectively its behavior and the definition of its knowledge is often extended with Automated Reasoning techniques to realize more 'intelligent' and adaptive agents. For example, the Web Ontology Language (OWL) [73], which has its origins in description logic, is a widely used language to define the agent's knowledge. In first order logic or OWL, inferencing about incomplete knowledge is difficult and led to the definition of negation as failure. This non-classical logic feature is used in the well-known declarative language Answer Set Programming (ASP) [74]. This non-monotonic logic combines logic programming with satisfiability checking for search problems [58]. ASP is often used for agent decision making purposes [75,76] in which ASP is combined with BDI agents to realize emotional behaviors respectively to model the whole knowledge and decision process. Beside these examples, Automated Reasoning methods are also used to enabling agents to synthesize new plans for unknown situations. Examples are Meneguzzi et al. [77] and Hilburn et al. [78] in which BDI respectively BT agents are extended with classical planning. Bauters et al. [79] presents a hybrid BDI-POMDP (Partially Observable Markov Decision Process) approach to realize agent planning under uncertainty. The former mentioned extensions are examples for deductive reasoning. Inductive reasoning techniques are also used for agents. In Gluz&Jaques [80] for example, Bayesian Decision Networks (BDN) are combined with a BDI agent to reason about the intensity of emotional behaviors. Zinnikus et al. [81] present another agent that uses BDN in combination with OWL to reason about possible symptoms of predicted shop floor failures. Learning techniques are common for classifying agent behaviors and to decide which behavior fits best in new situations, such as case based reasoning [82] or by extending the BT paradigm with reinforcement learning in [83].

3.5 Sequencing, co-simulation and constraint models (WP5)

Modeling of complex engineering system usually integrates physical, software and networking features [84]. Such systems are independently developed and distributed by different teams. In order to owe model inter-exchangeability and draw generic solution, state based activity definition, model constraining and co-simulation are used to analyze the literature as follows.

3.5.1 Sequencing

A frequently used technique for modeling and controlling the execution of animations in game engines like Unity3D [18] or Unreal [20] are state machines. The transition from one state respectively animation to a subsequent state takes place by means of manually created blending which are triggered by parametrized events that are issued by an execution environment. Predefining context dependent animation sequences or plans by using graph based techniques, like FSMs or BTs, is intuitive but time consuming and limited to specific situations, thus not adaptable to unexpected situations or other scenes.

Instead of solving animation sequencing in an imperative way, describing the problem logically allows the automated proof-based search of problem solving action sequences. Classical planning is the simplest way to solve planning problems, logically described as initial and desired goal state propositions and action rules with preconditions and effects. The best-known representative classical planning language, also used in games [85] to execute Non-Player-Characters (NPC) - there designated as goal oriented action planning (GOAP) - is the action *A* language [86] or STRIPS [87]. Generated plans are sequences in which no parallel or disjunctive actions occur. Another formal logic-based and more unspecialized and expressive paradigm for automated reasoning is logic programming. With logic programming languages like Prolog [88] or ASP, problems are formulated with facts and rules, which are used by a problem-solver to find one or more solutions. Using this paradigm several calculi [76,89,90] like Situation Calculus [91], Discrete Event Calculus (DEC) [92], Allen's Calculus [93] or Region Connection Calculus (RCC) [94], can be used to represent continuous respectively event-based domain changes or spatio-temporal relations.

3.5.2 Model constraint

Constraints and constraint sets are well known in CAD modelling. There, engineers are required to identify constraint information for mating parts by manually selecting the mating surfaces, axes and/or edges to assemble the parts. For complex assemblies, this methodology obscures the impact of individual mating specifications on the assembly process, for example ensuring accessibility for part or assessing the effects of changing assembly sequences[95]. When using this constraint modeling approach for ergonomics simulations, extensive manual effort is required to ensure not only kinematic consistency but prevent implausible or awkward human motions to be demanded by the constraints. Automating such domain-specific problems often leads to combinatorial complexity, e.g. finding collision-free gripping position of a robot arm in a shop floor scenario, and has many restrictive conditions like temporal or geometrical constraints. These constraints have to be defined in the planning problem space, which is why it is common to extend host languages with constraint primitives [96]. Efforts to simplify such approaches by using physics models have led to a number of solutions such as Dynamicus of the University of Chemnitz [2]. These solutions are able to adapt constraint motions so that they are physically more plausible but lack context and process information. Furthermore, tightly constrained situations as they are common e.g. in assembly in deep cavities lead to numerical instabilities [97], which poses a limitation on this type of constraints. A radically different approach to modeling constraints has been introduced from computer graphics. There, the idea is that the human motion is inherently variant rich and that the constraints may limit motions both spatially and time-wise by only addressing specific joint target positions rather than their whole trajectory [47]. The constraints could be constrained as little as possible, which is a paradigm change to the CAD based approach that has a single, optimal motion as its goal. As a consequence, an infinite set of possible motions is constrained as much as possible leaving motion corridors open [98]. This approach is similar to how natural language work plans are written. Therefore, supporting such a constraint approach could simplify practical application of an MMU.

3.5.3 Co-simulation

A unified language that entertains behavior theory and simulation techniques is necessary to integrate multi-domain systems into interchangeable simulation engines. The co-simulation approach is implemented in different engineering problems such as robotics [99,100], automotive [101], electricity production and distribution [102], heating ventilation and air conditioning [103], integrated circuit design [104] and maritime [105]. The most commonly reported co-simulation scenario involves physics based simulation [106] and data driven simulation [107–109].

4 Summary and Conclusions

To summarize, simulation and digital modelling activities are increasingly being used in the automotive industry in addition to a large number of different key industries. This underscores the growing importance of virtual technologies to improve productivity and reduce cost. The simulation of mechanical and mechatronic components has been described e.g. already extensively investigated in smart factory-related projects. By comparison, the simulation of human movements is still in its infancy. While some solutions offer the ability to model human movements in a realistic manner, they are currently either subject to a tremendous manual effort or can only be used in constrained environments (e.g., viewing static poses). On the other hand, some tools allow a holistic view of complex processes - such as those found in an assembly line - but at the expense of realism. Due to the lack of a holistic simulation concept, most questions must therefore be modelled manually, which, however, inevitably involves a lot of effort and thus high costs.

The MOSIM project has the overall objective of changing this situation by creating a holistic simulation approach. In particular, interoperable concepts and approaches are to be developed that significantly increase the degree of reality of software for the simulation of human movements. At the same time, the manual preparation and follow-up effort is to be drastically reduced or automated by methods of artificial intelligence and decision-making. To meet these ambitious goals, it is planned that the Standard Functional Mock-Up Interface (FMI), developed within the framework of the ITEA2 project MODELISAR, be extended to human motion components, whereby the respective algorithm for generating motion in a black box with a defined one and output is encapsulated. The resulting Motion Model Units (MMU) allow a nearly unlimited combination of different approaches to modeling human movements within a common simulation platform, which monitors the execution of the various building blocks in analogy to a co-simulator (e.g. "run", "reach","grasp", "withdraw"). In this way it is possible for the first time to combine specialized algorithms - e.g. statistical approaches for the simulation of running and high-precision path planning algorithms for the construction of parts - through their symbiosis the strengths are complemented and the respective weaknesses are compensated. Such an approach enhances the market potential of human simulation in several areas.

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