Validation of an Ontology-based Approach for Enhancing Human Simulation in General Assembly Environments

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Abstract—**Ergonomic simulation plays an important role as a decision-support tool when validating product designs, assembly processes, and manufacturing operation designs to improve the safety of workers in their associated work environments. In order to maintain competitiveness in the recent dynamic global marketplace, industrial companies are achieving cost savings through the application of ergonomic digital human simulation in the early phases of the product lifecycle process. Nevertheless, resulting benefits can be reduced or even over powered because of the high time, effort and cost requirement needed to build simulation models. In this paper, we assess an ontology-based approach for enhancing human simulation to overcome these challenges. This approach consists of using an ontology model to store re-usable virtual assembly simulation knowledge. Information stored in the ontology helps to build simulation environments quickly using an operator task library to implement digital human dynamic motions. This paper presents a detailed case study using an automotive headlamp installation task scenario to validate the approach. The resulting proof of concept system integrates a General Motors general assembly ontology, University of Michigan human motion models and the operator task library with the Siemens Classic Jack commercial digital human modeling software.**

Index Terms—**Digital Human Model (DHM), Human Simulation, Ontology, Product Lifecycle Management (PLM)**

1. Introduction

To be competitive in today's challenging economy, companies are faced with the growing demand to shorten the time to market and increasing complexity in products and the required production systems. As a result, manufacturing companies are focused on shortening the product development process. There are a number of emerging IT technologies to support achieving these goals including the use of "Virtual Prototyping". According to Wang, "Virtual Prototype" is a digital mock-up that can be simulated in the early product lifecycle to meet different requirements of testing and evaluation [1]. Thus, "Virtual Prototyping" has played an important role as a decision-support tool.

In support of the virtual prototyping concept, human simulation has been developed as one of the tools of choice to design, test and modify manufacturing systems of today. Human simulations are used to analyze postures and motions of a worker and their associated work environments. Product Lifecycle Management (PLM) solution companies have developed simulation software to support the creation of industry specific virtual environments using available CAD data and the digital human model (DHM) [2]. The human simulation tools available today are vastly improved in recent years. However, with increased competitive pressure for product quality and features, and reduced time for product development process, industry is requiring further efficiency improvements in PLM simulation software and methods. Moreover, though a number of active study and research projects are targeted to improve DHM functionality, benefits of human simulation are still sometimes overshadowed by the requirement for time, effort, and cost needed to build and successfully use the resulting models [3]. For this reason, there is a strong need to develop simulation capability and a methodology that is able to improve the human simulation process, so good product program decisions are made quickly and efficiently.

General Motors (GM) has developed a general assembly (GA) ontology for the purpose of supporting virtual manufacturing applications like the digital human model.

In this paper, we validate the ontology-based approach for enhancing the process of creating human simulations. Updates to GM's ontology model and a proof of concept of simulation data extraction program are developed to support the headlamp installation operation. And the operator task library is also constructed to generate dynamic motions for the DHM. This approach also uses an integrated graphical user interface to drive motions for the digital human within this proof concept system. Section 2 provides a background and literature review. The detailed concept for this approach is presented in Section 3. Section 4 describes the case study. And the benefits of the research and opportunities for further work are outlined in Section 5.

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2. Background and Literature Review

2.1 Human Simulation

In manufacturing industry, though production operations are being automated and industrial robots are being developed for repetitive and dangerous tasks, many elements of the production process are still highly dependent on human operators. Therefore, ergonomic simulation is desired during the early engineering phases of a program to ensure the safety of workers in their associated work environment and to validate manufacturing processes and designs. Early ergonomic simulation is an important practice because it accomplishes these safety and efficiency goals at a lower cost by reducing the need for physical validation and changes to tooling and equipment late in the product development process.

Over the last 20 years, software has supported digital human simulation and analysis through many improvements. For instance, in recent years there have been improvements in anthropometry and analysis in commercially available software such as SAMMIE, JACK, RAMSIS, and SAFEWORK [1]. This software has made it possible for ergonomists and simulation engineers to simulate, analyze and optimize manufacturing systems for ergonomics during the early design phase. However, when performing human simulation, the simulation engineer still generates motions and postures manually or they must use motion capture systems to drive the DHM. Therefore, current research and commercial software developments focus on improving the functionality of the DHM to provide more accurate posture and motion algorithms.

Product lifecycle management (PLM) allows a company's engineering contents to be developed and integrated with business processes through the product lifecycle. PLM extends PPR (product, process and manufacturing resource) content knowledge into other enterprise business processes by coupling e-business technologies with applications focused on the product development and production, such as ergonomic analysis [4]. Therefore, recent research looks at human simulation from product lifecycle management (PLM) perspective in order to enhance human simulation processes and capability. Some examples are included below.

J. Laring *et al.* describe methodologies and supportive tools to handle the introduction and administration of ergonomic simulation tools for manufacturing. The research approaches ergonomic simulation with the engineering process perspective, so an attempt is made to enhance the simulation process by creating a web-based handbook for gathering simulation knowledge [5].

Research by Lars Hanson *et al.* focuses on a design and evaluation guide and documentation system to prepare for extensive, effective and efficient use of human modeling tools in industry. With an experienced and educated tool user and a complete human simulations system, consisting of a process, a tool and a database, it may be possible to reduce the number of physical prototypes. This objective is very attractive from time and cost perspectives, particularly in vehicle development companies [6].

M. Annarumma *et al.* show a methodology based on preventive ergonomics and feasibility analyses of assembly tasks, simulating a work cell in order to maximize human safety and performance, and analyze manikin interaction in the virtual environment. The developed tool is a link between the virtual product and the virtual factory, assuring a two-way communication between them [2].

According to M. Geyer and B. Rösch, ergonomic knowledge and best practices can be captured and reused for modeling. And e-Manufacturing provides a profound platform to optimize production planning throughout the extended enterprise. The research shows how e-Manufacturing has an impact on human modeling enhancing the ergonomic simulation process [7].

Gun Yeon Kim *et al.* focus on achieving concurrent and integrated ergonomic analysis. In the research, they define PPR^{+H} (Product, Process, Resource, Human) schema to manage and integrate all the information necessary for analysis. And the PPR^{+H} integrator is developed to extract PPR^{+H} information from data management systems used in PLM [4].

2.2 Ontology

The term "ontology" has its origin in philosophy, and is used to specify a conceptualization. According to Tom Gruber, the ontology is a description of concepts and relationships that can exist for an agent or a community of agents [8]. Actually, there are a number of ontology definitions from various fields, but most definitions are just expressional difference. Recently, ontology work is widely used in knowledge engineering, artificial intelligence, computer science and in new emerging fields like the semantic web [9]. However, ontology application reported in the manufacturing domain is limited [10]. The surveyed literature in the manufacturing domain is summarized by the following three aspects: representation of manufacturing knowledge, application interoperability and sharing of manufacturing resources. A discussion of each is included below.

1) Management of manufacturing knowledge

The range in applications which fall into this category is broad in scope. Examples include terminology definitions which are shared across an organization, industry or geographical regions across the globe. We also include applications which map terminology, language and/or knowledge from one ontology to another and knowledge verification. Examples of applications which utilize the management of manufacturing knowledge include production planning, scheduling, diagnostic and natural language processing. Two examples are provided below.

Kyoung-Yun Kim *et al.* present an ontology-based representation method for differentiating assembly joints in product design. By relating concepts rather than just defining data syntax, assembly and joining concepts, various geometrically and topologically similar joints are differentiated in a standard and machine-interpretable manner [11].

Yi Jianjun *et al.* research a knowledge management architecture for life cycle engineering design (LCED) in order to support design teams to create products while considering the entire product lifecycle. The research describes the definition of the domain-specific ontology based on LCED and the detailed construction of CAD agents [12].

2) Application for manufacturing interoperability

Application examples in this category include control and interoperability. The Process Specification Language (PSL) is an ontology developed at the National Institute of Standards and Technology (NIST) for description of basic manufacturing, engineering and business processes. It aims to facilitate correct and complete exchange of process information among manufacturing systems such as scheduling, process modeling, process planning, production planning and simulation as a neutral interchange ontology [13].

3) Sharing of manufacturing resources

By utilizing the world wide web in conjunction with ontology knowledge bases, better utilization of resources can be achieved by sharing them across a network. Examples of this category include distributed services and collaboration.

Kyoung-Yun Kim *et al.* propose an ontology-based assembly design (AsD) that serves as a formal, explicit specification of assembly design so assembly knowledge is both machine-interpretable and shareable. The developed AsD ontology and browser take full advantages of SWRL and OWL technologies. Therefore, it can be utilized in various activities related to assembly design modeling collaboration [14].

The Variation Reduction Adviser (VRA) system used within GM is a database containing problems encountered in processes and their possible solutions. Sugato Chakrabarty *et al.* show an approach to extract useful information from VRA database using a body shop domain ontology. The ontology-guided approach makes possible the ability to share the problems and the solutions in body shop operations [15].

3. METHOD

The aim of this research is focused on enhancing the human simulation process in GA environments. We are validating GM's proposal to use an ontology as the method to simplify constructing human simulation. Three development phases were involved in the method to construct a proof of concept system and task definition menu, i.e. (1) Updates to the existing GM GA ontology and development of the simulation data extraction program, (2) Generation of an operator task library and (3) Integration the ontology-based human simulation with commercial simulation software. Fig. 1 outlines the proof of concept system architecture resulting from this research. The details are described in the following sections.

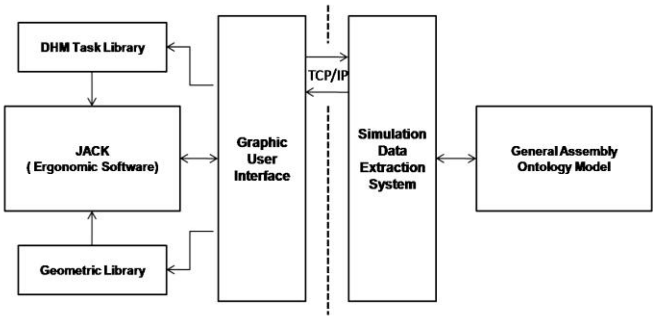

Fig. 1 Ontology-based human simulation architecture

3.1 UPDATE TO THE GM GA ONTOLOGY MODEL AND DEVELOPMENT OF SIMULATION DATA EXTRACTION PROGRAM

An ontology consists of classes, properties, and instances. A class defines a concept in a domain. Instances of classes are associated to classes via properties. And properties can be used to state relationships between instances, or between instances and values. This application utilizes the product and process class elements from the GM GA ontology. For instance, a process class includes operational information required to define the sequence of unit tasks that comprise work performed by the DHM. The process class enables the user to drive the operation and DHM at a much higher level command than is provided by commercial simulation software.

Table 1 shows examples of properties that present relationships between classes. For instance, the "Operator Instructions" property is used to link operations and its domain in the Vehicle Assembly Operations class. And the "Secure Tool" property is used to indicate a tool instance. Consequently, properties play a role in creating relationships between simulation knowledge elements. The completed GA ontology model is used to create simulation environments and generate motions for the DHM.

Table 1
Examples of properties

Property	Domain
Operator Instructions	Vehicle Assembly Operations
Secure Tool	Product
Layout	Product
Next Vehicle Assembly Operation	Vehicle Assembly Operations
Pallet	Product
Ordered Installed Parts	Plant Process

The GM GA ontology was developed using Protégé 3.4 to implement the required knowledge definitions of the ontology model. Protégé is free software that was developed by the medical information center at Stanford University. It is well suited as a tool to construct domain models for knowledge-based applications in the form of ontologies. And the extraction of simulation data from the completed GA

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ontology model is implemented through the Java script ontology API.

3.2 Generation of an Operator Task Library

The operator task library is a set of decomposed tasks defined in the form of function calls. A complex operation may be segmented into unit tasks that can be executed separately and connected via transitional motions. For instance, an operation such as “get a part” consists of unit tasks such as gaze, walk, reach and attain. The operation is implemented by combining unit tasks in the operator task library. The task library relies heavily on use of the HUMOSIM Framework Reference Implementation developed by Matt Reed *et al.* at the University of Michigan [16]. The HUMOSIM Framework provides a mid-level definition of tasks for the DHM. It handles planning realistic digital human motion and the coordination of motions across individual digital human joints.

3.3 Integration with Human Simulation Software

The proposed approach is integrated with the Siemens Classic Jack software. Fig. 2 shows the graphical user interface (GUI) integrated inside Jack. The graphical GUI makes it possible to build a human simulation environment more quickly by retrieving re-usable simulation data from the GA ontology model. This data is used to populate function calls to the HUMOSIM Framework resulting in realistic DHM motion. It has the advantage of allowing non-expert users to simulate operations intuitively through a high level command user interface than provided by the current Jack software.

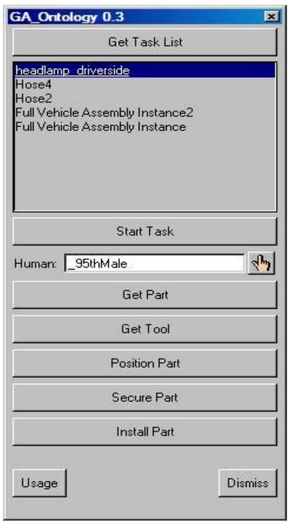

Fig. 2 Graphical user interface integrated in the Jack Software

4. Application on Case Study

In order to validate the approach, this research includes a headlamp installation task case study for comparison purposes. The same case study was previously used to validate the HUMOSIM Framework [16]. The case study is described as follows in Fig. 3. To initiate the headlamp installation process setup, the sequence of operations was obtained. Then, each operation was decomposed into unit tasks as shown Table 2. And the sequence of unit tasks is stored in the GA ontology model in order to direct work for the operation at the highest level. It is implemented by combining unit tasks in the operator task library. Next, simulation data required by the HUMOSIM Framework to build the simulation environment is stored in the GA ontology model and is represented as instances of classes and relationships between classes that are generated through properties. The GA ontology model includes knowledge about how to perform the operations in the form of handprints for example.

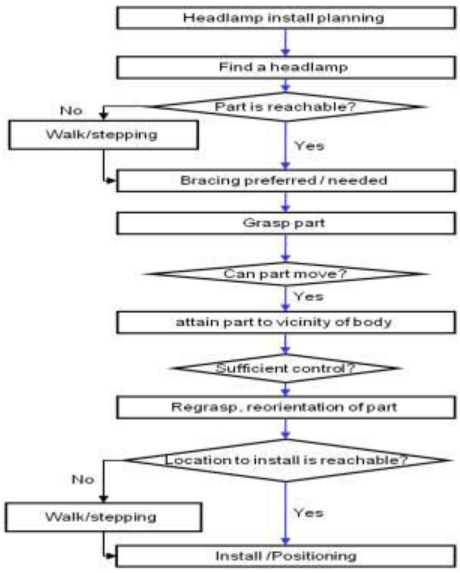

Fig 3. Headlamp installation task scenario

Table 2
Headlamp installation job element sheet

Operations	Job Elements	Unit Tasks
Get Headlamp		
	Find the Headlamp	Gaze_part
	Walk to the Headlamp	Locate_worker
	Reach to the Headlamp	Reach_part
	Attain the Headlamp	Attain_part
Install Headlamp		
	Regrasp the Headlamp	Regrasp_part
	Find the Car Body	Gaze_part
	Walk to the Car Body	Locate_worker
	Position the Headlamp to the Car Body	Position_part
	Force the Headlamp	Hold_part
	Release the Headlamp	Release_part
Secure the bolt		
	Find the RightAngle_Tool	Gaze_part
	Walk to the RightAngle_Tool	Locate_worker
	Reach to the RightAngle_Tool	Reach_part
	Attain the RightAngle_Tool	Attain_part
	Find the Car Body	Gaze_part
	Walk to the Car Body	Locate_worker
	Secure the bolt	Secure_part

After building the GA ontology model, the human simulation was completed using menus implemented within Jack. The simulation result is shown in Fig. 4. As shown, the simulation engineer is able to simulate the assembly tasks without spending time searching for and retrieving each element from libraries. And the operation specified at a high level reduces the repetitive, tedious and manual work typically required to

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generate digital human motions.

The headlamp case study has shown this approach improves the simulation process by significantly reducing simulation creation time. In addition to the headlamp installation, a heater hose installation was also completed using the proof of concept system, showing a greater reduction in simulation creation time. The additional savings are attributed to re-using simulation elements within the ontology. Although the results are promising, it's important to note this work includes only two case studies, so additional development and testing is required for the results to be conclusive. And significant work is required to transform a proof-of-concept system to a usable tool.

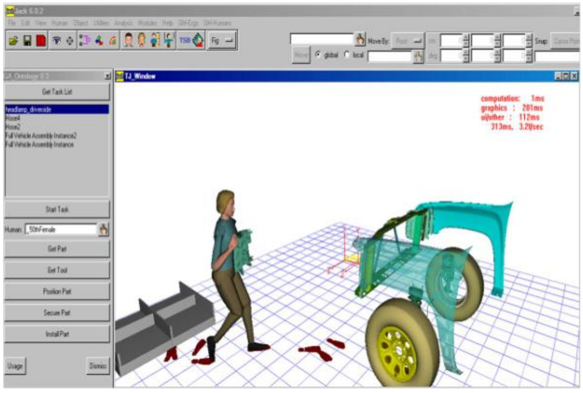

Fig. 4 Headlamp installation task simulation

5. Conclusion and Future Work

Human simulation is integrated into the product life cycle to improve simulation and validation within the product development processes. As a result it is able to produce results from human simulation faster and more efficiently. This research enables a significant time saving and alleviates needed efforts to collect the required information by making available consistent simulation data from the GA ontology model and the operator task library. In addition, the integration with Jack reduced the tedious and manual work to collect required simulation elements and generate motions for the DHM.

The ontology is a useful method to share and reuse virtual manufacturing knowledge by providing architecture for well constructed knowledge representation, integrated in the simulation PLM environment. We suggest future work should include extensions for the GM GA ontology to represent detailed definitions for human elements, process time and manufacturing assembly strategy class definitions. And, the GA ontology research may be extended to include manufacturing best practices knowledge for re-use within human simulation and analysis.

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