IMMA – INTELLIGENTLY MOVING MANIKINS IN AUTOMOTIVE APPLICATIONS

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INTRODUCTION

Digital human modelling (DHM) has been introduced in the product and production development process to provide the possibility of early analysis and verification of human-product and human-production system interaction. Digital human modelling is relatively widely used within automotive industry (Paul et al., 2012). Digital human modelling can be used to analyse both human postures and motions. Several techniques have been explored for the generation of manikin motions. Neural networks, a structure that should imitate the human brain, and fuzzy logics, a logic that should imitate human reasoning, have been tested in combination (Hanson et al., 1999). Currently no commercial digital human modelling tool on the market uses this combination to generate motions. In Siemens' ergonomics simulation and visualisation tools two approaches are currently used: a task-based simulation approach with inverse kinematics (Raschke et al., 2005), and an approach that modifies root motions gathered from real humans using motion capture systems (Park et al., 2008). Motion captured recorded motions are also used in EMA where base motions from a reference database, similar to base tasks in predetermined motion time systems, is put together into new unique motion combinations (Fritzsche et al., 2011). Even though these approaches are available, most commonly the manikin is manually manipulated joint by joint, which gives drawbacks such as that manual adjustment is time consuming and posture and motion results may vary, both within and between tool users (Lämkull et al., 2008). From an industrial point of view such variation within the process is not a sustainable way of working. Frequently the validity of the manually generated manikin postures and motions is questioned. Therefore, researchers and industry use motion capture systems in combination with ergonomics simulation and visualisation tools. Motion capture systems require typically a laboratory like environment and physical prototypes. Hence, in using such a set-up, several of the advantages with virtual design and manufacturing disappear or are reduced. Therefore there is a call for valid motion generators in digital human modelling tools in order to support proactive ergonomics (Chaffin, 2005).

Automatic path planning, to find collision free motions of moving objects, is a well-established research area. Complete algorithms are of little industrial relevance due to the complexity of the problem (PSPACE-hard for polyhedral models, Canny, 1998). Instead, sampling based techniques, trading completeness for speed and simplicity, have important advantages in an industry context. Common for these methods are the needs for efficient collision detection, nearest neighbour searching, graph searching and graph representation. The two most popular methods are Probabilistic Roadmap Methods (PRM) (Bohlin and Kavraki, 2000) and Rapidly-Exploring Random Trees (RRT) (LaValle and Kuffner, 1999).

The aim of the research presented here was to develop a user friendly, non-expert digital human modelling tool with a manikin motion generator, based on automatic path planning techniques, that finds a collision free and ergonomic motion for a part and the human who is assembling the part, seen as a system. In this paper the developed digital human modelling tool is illustrated by two cases made in an automotive production context.

METHOD

The IMMA (Intelligently Moving Manikins) DHM tool was developed in close cooperation between vehicle industry and academia in Sweden. The academia consortium consisted of expertise within applied mathematics as well as ergonomics. The IMMA tool acted as a continuously developed demonstrator used in the project to implement the knowledge gained from the research. The demonstrator was used to presented ideas and be an inspiration source for new functions. Industry and academia were holding regular meetings for information, evaluation, verification and training.

The development of the tool was largely case driven. Case descriptions and CAD geometry were provided by the industry. The cases were of the type; a worker assembling a small rigid part in a narrow area, a worker assembling a large rigid part with lifting device in a narrow area, a worker assembling flexible cables in an open area as well as a driver sitting in the seat and operating controls.

RESULT

As a basic functionality the IMMA tool is able to handle regular CAD geometry. The geometry can for example describe the human (Gustafsson et al., 2012), passive rigid objects, such as the workstation and the product on which the part is to be assembled, as well as active objects, such as the rigid parts to be assembled and tools. IMMA is also equipped with advanced CAD functionality to simulate flexible materials such cables and hoses, as well as the interaction between the human and flexible materials, e.g. to calculate resulting reaction forces (Delfs et al, 2014).

The manikin, or indeed an entire manikin family, is controlled by defining tasks using a high level instruction language (Mårdberg et al., 2013). The high level language is based on the use of task keywords, e.g. “place”, inspired by predetermined motion time systems such as MOST (Zandin, 2003). To support the definition of tasks, a detailed library of hand grips is available. The manikin task instructions are similar to instructions given to the assembly workers in the plant. The instructions given are verified and contradictory tasks are prohibited. Tasks necessary to be performed by the manikin to be able to fulfil the high level descriptions are automatically added on a lower level. Tasks on the low level are described as motion paths that the human or the handled part should follow.

The motions are generated by inverse kinematics where a comfort function seeks to optimize comfort while fulfilling current constrains. Constraints are coming from the manikin itself, e.g. joint angles and body geometry, the surrounding environment, e.g. the workplace, the parts handled, e.g. the weight of the object, and the task to be performed, e.g. a collision free path for the part to be followed. The comfort function penalizes for example certain joint angles, high joint moments and high contact forces and short distances to the vicinity. Concurrently with the optimization of comfort, stability and balance are automatically considered by the algorithms. The manikin is considered being in balance when the sum of the external forces and torques equals zero (Bohlin et al., 2012). External forces are acting on support points such as feet and hands. The forces in the support points are automatically calculated by inverse kinematics. A support/contact point is specified by the tool user, and in such a point information about a part’s properties, e.g. weight, is considered. Stability is added on top of balance. A posture in balance is stable if all forces and torques can be derived from a potential function and if the gradient of the potential function is larger than zero for every virtual displacement (Delfs et al., 2013). The manikin avoids both collision with external objects and it self. Through the use of a complexity reducing heuristics, the tool can handle collision avoidance in real time. IPS (Industrial Path Solutions) is used for generating a collision free path for the part in complex narrow environments (Bohlin and Kavraki, 2000). The manikin set to assemble the part is however allowed to diverge from the path to some degree to obtain better ergonomics as long as the path for the part can be guaranteed collision free.

The manikin has 82 segments and 162 joints connected together in a hierarchical tree structure.

Each segment has mass, centre of gravity as well as adjustable length. The inner biomechanical model and the outer skin model build up a manikin that aims to represent a human well enough for the application it is created for, i.e. simulation of human-product and human-production system interaction. Still, all humans are unique. Therefore the IMMA tool includes methods for creating a manikin family, i.e. a set of manikins that will represent the anthropometric diversity among humans within the user group that is to be represented. Several methods can be used and combined in the IMMA tool for creating the family members, either axis cases, box cases or centre cases (Brolin et al., 2012). Principal component analysis can be used for reducing the number of family members when the number of key anthropometric measurements is high. The IMMA tool also enables mixing anthropometric databases, e.g. to represent a mixture of nationalities. All family members follow instructions given to a unique member by using batch functionality in the software that runs through all members. When all manikins in a family have performed the task, post ergonomics assessment methods can be used to retrieve detailed ergonomics information. The methods currently included are either company specific methods inspired by observation based ergonomics assessment methods, e.g. RULA (McAtamney and Corlett, 1993), or methods that consider the combination of amplitude and duration of biomechanical exposure. One method of the latter type is calculating exposure variables and then matches this exposure combination with exposure combinations in a reference database (Keyvani et al., 2013). The reference database includes exposure and human response for a number of work classes. The idea with the references database and the exposure matching is that the simulated work is likely to cause a similar human response as the best match.

Case 1

The truck cabin has a large number of cables that are to be mounted. Cables are typically attached with clips to give a fast manufacturing process. In this illustrative case the following major steps were performed:

- The geometry was loaded into the IMMA tool and the cables imported were “put alive” using the flexible material simulator functionality (Figure 1).
- Contact points for support, clips positions and clips push forces were defined in the surrounding environment.
- The anthropometric key variables were specified and a manikin family was created.
- One member of the family was positioned close to the cabin. The manikin was instructed to place its left hand at the contact point for support and use a thumb push grip to fixate the cable in the clips positions.
- The simulation was started. The upper body motions were automatically calculated for each family member.
- A first visual verification was done by playback of the simulated work.
- A detailed ergonomics assessment was done using a company specific method (Figure 2).

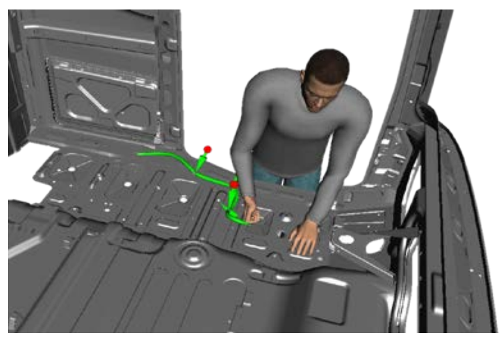

Figure 1. Manikin assembling cables with clips.

Figure 2. Ergonomics assessment result of the assembly task using a company specific method.

Case 2

The car is full of parts what should be assembled in narrow areas. In this illustrative case the following major steps were performed:

- The vehicle and surrounding geometry, a logistics rack, was loaded into the tool.
- The part to be assembled was specified and part properties was added.
- A collision free path for the part to be assembled was created using a path planning tool.
- Contact points were defined on the part to be assembled and in the surrounding environment.
- The anthropometric key variables were specified and a family was created.
- One member of the family was instructed to pick up the part to be assembled by using a right hand power grip, and then to assemble the part using right hand and the pre-planned part path as well as to take support with the left hand at the contact point.
- The simulation was started. For each manikin, the IMMA tool automatically created a unique path for full body motion to move the manikin closer to the logistics rack. When the part to be assembled is within a comfortable reach the manikin grasps the object. To connect to the pre-planned collision free part path the tool adds another comfortable full body motion path holding the part. Finally, the tool modifies the pre-planned part path to generate a collision free path for the manikin and the part that is comfortable for the manikin while fulfilling present constrains (Figure 3).
- A first visual verification was done by playback of the simulated work.

Figure 3. Manikin assembling a part in a narrow area.

DISCUSSION

The developed IMMA tool is argued to be a user friendly, non-expert digital human modelling tool with a manikin motion generator that finds a collision free and ergonomic motion for a part and the human who is assembling the part, seen as a system. The tool conforms to Lövgren's (1993) four usability criterion: relevant, efficiency, learnability and attitude. The industry defined the need so the overall relevance of the tool is justified. The use of the tool is highly automated in order to offer an efficient simulation work. An example of this is that the user controls the manikin with basic commands and then mathematical algorithms and computer power are doing the hard, and commonly time consuming, work. Early informal evaluations of IMMA done at industry indicate large savings of time, and better repeatability, compared with previous work methods where manikins are manipulated joint by joint. This suggests that the current version of the IMMA tool well matches the efficiency criteria.

When arranging the IMMA research project the industry asked for a non-expert tool. This objective is closely associated to the learnability criteria. In order to generate a pre-planned path for a part in a narrow area the IMMA user in brief only has to define the part to be planned and the start and the end positions. When the calculation button is pushed the mathematical algorithms and the computer are doing the work and a collision free path is suggested. This, in combination with that the manikin is instructed with a high level language similar to instructions written in work instruction sheets for the workers at the plant, makes the usage of the tool easy to learn and remember and suitable for non-experts. The tool can also be used by experts and is indeed preferably used by many roles involved in the product and production development process, e.g. designers, manufacturing engineers and ergonomists, to facilitate discussions and to share experiences between different users, i.e. both non-experts and experts and specialists.

The industry was involved in arranging and performing the research and development of the IMMA tool and their attitude, as end users of the tool, towards the tool and its further development is positive.

The IMMA tool is based on automatic path planning techniques for finding collision free and ergonomic motions for a part and the human who is assembling the part. The path planning algorithms, and the associated tool IPS (Industrial Path Solutions) (Bohlin, R. and Kavraki, L.E., 2000) is used today in industry for path planning of parts. IPS is a part of an IT system landscape and work processes are already developed. Hence, the addition of IMMA, i.e. having the opportunity to add a digital human model to verify ergonomics, will be a minor update of their IT landscape and work processes. While being a minor update, the addition of IMMA will mean that valuable information, related to analysis and verification of human-product and human-production system interaction, can be retrieved early in the product and production development process.

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