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Using a formal high-level language to instruct manikins to assemble cables

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Abstract

In this paper, a formal high-level language is used to generate simulations where a manikin assembles flexible cables. The language generates assembly instructions for the manikin, which automatically performs the corresponding assembly motion with as good ergonomic as possible. Due to weight, stiffness and narrow regions, it may be difficult to perform an assembly of the cable. Our approach allows us to verify that it may be performed in an ergonomically sound way. The generated instructions are formally verified to ensure that assembly order is held and to prevent erroneous assembly states. The simulations have been made on industrial test cases.

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1. Introduction

Today, an electronic device is a commonly assembled part in the manufacturing industry. Usually, these devices needs to be further connected to other devices, to for instance get power supply and information from actuators. Thus, an assembled product may include several operations where cables need to be routed.

These cables have to be manually routed through the assembly operation. Hence, all the forces and torques that occurs due to weight, stiffness and shearing from the cable, also needs to be handled throughout the routing. Moreover, due to compact constructions, the routing may occur in narrow and inaccessible regions.

In order to reach a high quality production, it is important to ensure that it is both possible to correctly assemble the cables, and that it is possible to make in an ergonomic sound way.

A Digital Human Modeling software is an important tool in virtual manufacturing, which allows simulation of manual assembly work long before any physical product and work place has been built (Laring, 2004). Thus it is possible to solve design issues, troublesome assembly sequences and logistic bottlenecks early in the conceptual development. This reduces the cost of late design changes, increases the production quality and decreases the ramp-up time of a manufacturing process (Falck, et al., 2010).

A step towards integrating a manikin with flexible cables is presented by (Wegner, et al., 2013), and in the work of (Delfs, et al., 2013), it is shown how it is possible to integrate the cables in the kinematical skeleton of the manikin.

However, far from all assembly operations are simulated and evaluated even if all the necessary data is available. One reason for this is the time consuming and tedious work that is required to setup and to define all the realistic motions needed by a manikin to perform a simulation (Lämkull, 2009; Raschke, et al., 2005). In each assembly simulation, the user has to position the manikin at the workstation, adjust the manikin into the desired posture and select the correct grip. Moreover, to make the simulation relevant, the user must

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ensure that the manikin maintains balance during the simulation and that it avoids collision with objects in the environment.

In order to create a realistic simulation an assembly motion of a cable, the torques and forces from the cable needs to be included in the simulation.

Hence, even a small assembly case may be time consuming to simulate, and it is well motivated to find an easier way to construct assembly simulations.

A novel approach that uses a formal high-level language to instruct automated manikins to reduce the time needed to construct assembly simulations has been introduced in (Mårdberg, et al., 2013). This paper shows how this language also may be used to easily construct assembly simulations with flexible cables. The user define were the cable should be connected and then instruct the manikin with high-level instructions to perform the assembly.

This is possible by including the cables into the assembly model, as the instruction language, the manikin and all the objects used in the assembly are composed into the same discrete model (Mårdberg, et al., 2013). It is also formally verified, to ensure that it is valid.

The grammatical structure of the language divides the instructions into a hierarchical tree, where the lowest levels in the tree contains the basic instructions for maneuvering the manikin, such as Move, Position and Grasp, and the higher levels contain more abstract instructions such as Get and Assemble. Thus, a high-level instruction such as Assemble defines sequences of other instructions, whereas a low-level instruction such as Grasp corresponds to a direct instruction to the manikin.

This approach has been implemented in the manikin simulation software Intelligently Moving Manikins (IMMA) (Hanson, et al., 2011), and it has been tested on relevant assembly cases from the automotive industry. It is shown that it is possible to efficiently construct simulations where flexible cables are assembled.

The main contributions of this paper are that we based on the work proposed in (Delfs, et al., 2013) expand the assembly model and instruction language proposed in (Mårdberg, et al., 2013) to reduce the time needed to perform an assembly simulation with a flexible cable.

This paper is organized as follows. Section 2 covers the requirements of the presented approach, whereas Section 3 covers our modeling approach. Section 4 shows some case studies followed by discussion and future work in Section 5. Concluding remarks are found in Section 6.

2. Assembly model requirements

In this work it is shown that it is possible to automate the process of generating assembly simulations with flexible cables. However, this approach requires a model that contains an automated manikin, a formal instruction language and all the cables and geometries used in the assembly.

2.1. Automated manikin

A manikin can be said to be automated if it is able to automatically perform an assembly operation. Thus, if the manikin is instructed to grasp an object, then it should be able to automatically reposition itself and grasp the object without any further help from the user. Moreover, it is not sufficient for the manikin to just automatically perform the assembly operation; it also needs to maintain balance during the operation. The balance has to consider the body parts and the objects being carried as well as exterior forces and torques from the environment. Furthermore, it also needs to automatically avoid collision with the objects in the assembly station (Bohlin, et al., 2012; Delfs, et al., 2013).

2.2. Formal Language Definition

The set of available instructions that the manikin may perform during a simulation depends on the current state of the manikin and on the state of the objects in the assembly station. For instance, if the manikin grasps an object with both hands, it is then seen as impossible for the manikin to grasp another object.

The properties of objects, such as grasping points and mating points also help to define the set of available instructions for the manikin. Each low-level keyword must have a corresponding action in the simulation. A $Grasp$ instruction may only be used if there is an object that is available for the manikin to grasp.

It is also possible to consider the order in which the different parts should be assembled when constructing instruction sequences for the manikin. Thus, it is possible to prevent a manikin from performing an assembly instruction unless all the preconditions to that instruction are fulfilled.

2.3. Flexible Cable

The flexible cables used in the assembly are modeled as cosserat rods (Hermansson, et al., 2013). Manipulation handles, which may for instance be defined as clips clamped onto the cable, work as constrains for the cables, see Figure 1. Thus, properties of the material in the cable are represented by introducing reaction torques and forces into the handles. A cable is said to be placed in desired configuration when all constrains consisting of positions and orientation in all handles are in mechanical equilibrium (Hermansson, et al., 2013).

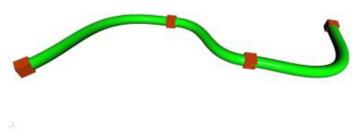

Figure 1: A cable with four manipulation handles.