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ScienceDirect

Procedia CIRP 23 (2014) 35 – 40

www.elsevier.com/locate/procedia

Conference on Assembly Technologies and Systems

Automatic Creation of Manikin Motions Affected by Cable Forces

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Abstract

Effective simulation of manual assembly operations considering ergonomic load and clearance demands requires detailed modeling of human body kinematics and motions, including balance and response to external forces.
In this paper we address the interaction of humans with flexible objects. By incorporating detailed physics simulation of flexible objects into the creation of ergonomically feasible human motions, we are able to ergonomically assess manual assembly operations involving cables and hoses.
The method is implemented and demonstrated on a challenging operation taken from the automotive industry; a wiring harness assembly.

Selection and peer-review under responsibility of the International Scientific Committee of 5th CATS 2014 in the person of the Conference Chair Prof. Dr. Matthias Putz matthias.putz@iwu.fraunhofer.de

Keywords: Digital Human Modeling; Inverse Kinematics; Flexible Materials;

1. Introduction

Although the degree of automation is increasing in manufacturing industries, many assembly operations are performed manually. To avoid injuries and to reach sustainable production of high quality, comfortable environments for the operators are vital, see [1]. Poor station layouts, poor product designs or badly chosen assembly sequences are common sources leading to unfavorable poses and motions. To keep costs low, preventive actions should be taken early in a project, raising the need for feasibility and ergonomics studies in virtual environments long before physical prototypes are available [1].

Today, more electrified and hybrid solutions are realized in the vehicles. As a consequence, the amount of cables and hoses that needs to be routed in order to connect the electronic devices has increased. The routing is usually made manually and performed in tight and narrow regions of already compactly designed vehicles. Moreover, the workers also have to consider the shear and strain during the routing of a cable or hose. The shear and strain adds extra forces and torques that an assembly worker needs to consider in order to fully performing an assembly, and may lead to awkward and uncomfortable positions. Thus, there is a need of efficient tools that allows possibility to evaluate the ergonomics of manual assembly operations involving flexible material where the full assembly motion is considered.

Simulations of manikins assembling flexible materials have been presented in [2], in which the digital human Jack [3] was combined with the IPS Cable Simulation software [4]. For each posture of the assembly motion, the force and torque needed in order to hold a cable in a specified position and orientation were transferred to the manikin, which had to repositioning itself in order to resist the forces and torques. In this article we extends the work presented in [5] [6] and take this approach in [2] one step further by letting the manikin change the location and orientation of the cable when it is not completely predefined.

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doi:10.1016/j.procir.2014.10.071

2. Flexible Cables

The simulation of manual assembly operations for ergonomics evaluation is typically done interactively. This way of working puts high performance demands on the software components. When studying the interaction between manikins and flexible objects, the engine for simulation of flexible objects need to be computationally efficient. See [7] for an overview of available methods.

The work presented here is based on the software module IPS Cable Simulation [8]. It is based on Cosserat rods, which are gaining in popularity, and in combination with new mathematical techniques and numerical procedures, reaches real time performance while retaining the necessary physical accuracy [4].

Flexible objects exist in a great variety. In what follows we let *cable* denote any slender flexible object, for example a hose, wire, wiring harness, or rubber sealing.

2.1. Cable Definition

The IPS Cable Simulation module allows quasi-static simulation of virtually any network of elastic cables – anisotropic materials, pre-deformations, arbitrary and varying cross section profiles. The generic input specifying the physical properties of a cable segment is the length density and effective stiffness parameters for bending (in two directions for asymmetric cross section profiles), twisting and stretching.

For a wire or a bundle, the individual strands and fibers are not simulated. Instead, a single cable with aggregated effective material properties is used. This is for example the situation in the test case presented later; the wiring harness is modeled by a number of connected segments, each including the wire bundle and a covering such as tape or a conduit.

For isotropic materials, the effective material properties for elementary cross section profiles like circular, rectangular and elliptic ones (possibly hollow), can be calculated from the density, Young's modulus and the Poisson's ratio.

2.2. Cable Clips

The cable is controlled by specifying boundary conditions, generally called *clips*. A clip can constrain the cable in space by restricting certain degrees of freedom for example fix position, fixed position and orientation, or fixed but with twisting allowed. The last type mimics the behavior of a cable routed through a ring. Furthermore, clips can either be fixed or free relative to arc length position. By connecting multiple clips from separate cable segments into groups that can move freely, any kind of cable branches, joints, and network can be represented [4].

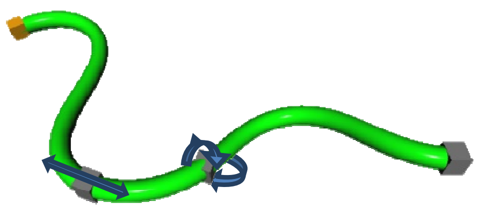

Figure 1: A cable with multiple clips of different types. Both end clips and the left interior clip completely lock the position and orientation of the cable, but the latter one allows the cable to glide through the clip. The right interior clip locks the position, but allows arbitrary rotation.

In our work, we use clips to specify the interaction points between manikins and cables. A manikin can grasp and reposition one or more clips which then in turn will affect the manikin through the torques and forces generated by the cable. A grasp is defined as when the manikins hand is locked into position relative to the clip.

3. Manikin Model

In this section we present the manikin model and the inverse kinematic problem which includes positioning, contact force, collision avoidance, comfort, stability and balance. It will also be described how the cable can directly influence the manikins' postures.

To describe operations and facilitate motion generation, it is common to equip the manikin with coordinate frames attached to end-effectors like hands and feet. The inverse kinematic problem is to find joint values such that the position and orientation of hands and feet matches certain target frames. This leads to an underdetermined system of equations since the number of joints exceeds the end-effectors' constraints. Due to this redundancy there exist a set of solutions, allowing us to consider ergonomics aspects, collision avoidance, and maximizing comfort when choosing one solution.

3.1. Kinematics

The manikin model is a simple tree of rigid links connected by joints. Each link has a fixed reference frame and we describe its position relative to its parent link by a rigid transformation $T(\vartheta)$. Here ϑ is the value of the joint between the link and its parent. For simplicity, each joint has one degree of freedom, so a wrist, for example, is composed by a series of joints and links.

To position the manikin in space, i.e. with respect to some global coordinate system, we introduced in [5], an exterior root as the origin and a chain of six additional links denoted exterior links – as opposed to the interior links representing the manikin itself. The six exterior links have three prismatic joints and three revolute joints respectively. Together, the exterior links mimic a rigid transformation that completely specifies the position of the lower lumbar. In turn, the lower lumbar represents an interior root, i.e. it is the ancestor of all interior links.

Note that the choice of the lower lumbar is not critical. In principal, any link could be the interior root, and the point is that the same root can be used though a complete simulation. No re-rooting or change of tree hierarchy will be needed.