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Robot Station Optimization for Minimizing Dress Pack Problems

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Abstract

Problems with robot dress packs are one of the major reasons for online adjustments of robot motions and for down time in robot stations. A factory study showed that many robots wear out more than one dress pack per year. The life length variation was in fact shown considerable, ranging from years to only months. The dress packs consist of attached cables and hoses which typically have significant impact on allowed robot configurations and motions in the station.

In this paper, we present novel simulation methods for improving robot configurations and motions during off-line programming and optimization of robot stations. The proposed method is applied to a stud welding station resulting in the elimination of several problems related to the dress packs.

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Keywords: automation; simulation; motion planning; optimization; robotics and dress packs

1. Introduction

In a highly automated production factory for complex assembled products there could be up to several hundreds of robots organized into lines and stations for handling and joining operations. Therefore, the factory is a huge investment and return on investment requires high product quality, factory throughput, equipment utilization, and flexibility as well as low energy consumption [1,2].

Many industrial robots are externally dressed with cables and hoses feeding the tool with signals, power, air, screws, paint and sealing material etc. These dress packs have serious impact on the allowed robot configurations and motions in a robot station. The reason is the risk of early breakage due to high stresses and wear. For example, a robot hose in a body shop cycles through the same motion every, say, minute. The hoses are often affected by large deformations, sometimes contacts with the robot links and in worst case with the surrounding geometries. This type of breakdown of robot cables is a big concern in the factory creating replacement cost and down time. A factory study at Volvo Cars showed that 47% of the robots wear out more than one dress package per year [3]. The life length variation was shown considerable, ranging from months to years. Out of all dress pack related breakdowns, 61% were considered to be major, i.e. takes more than 30 minutes to resolve [4]. The study also showed an existing potential to improve the situation with an estimation of 14% wear out instead of 47%, if appropriate actions were to be taken. Besides this, the robotic cable protection company REIKU claims that ”Almost 85% of Robotics and Automation ”downtime” can be directly attributed to cable or hose failure” [5]. Also [6,7] report that failing cables are the foremost cause of downtime for industrial robots. Robot programming experts, points at the root cause likely was the lack of proper optimization of the robot path [3]. Therefore, if the dress pack wear would be considered at an early stage of planning, then it would have a significant effect on the breakdowns.

Considering that for example a vehicle Body-in-White process involves hundreds of robots [2] shows the potential of improvements in the life length of robot cables. Today, the

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robot manufacturers provide rules of thumbs on how to avoid high stresses, and collisions are removed by experience and on-line adjustments. However, recent progress in real time simulation of cables [8] makes it possible to determine how robot cables are deformed during the robot motions. This together with technology for automatic path planning and line balancing [2] will in this paper be used to develop novel strategies for finding feasible robot configurations and improved motions with respect to equipment utilization/cycle time and life length of cables.

Despite the importance and potential, there exist only a few published methods on how to include a physical correct dress pack in off-line programming of robot stations [9,10] .

The paper has the following outline: In Section 2, the mechanical and mathematical model for real time simulation of dress packs is introduced. Then, in Section 3, an xml scheme for modeling and storing dress packs in a reusable way is defined. In Section 4, a scan2flex method for determining effective material properties of complex dress packs is described. Section 5 shows the state of the art of automatic optimizing of robot stations and the problems caused by not including the dress packs. Seeing that, Section 6 shows how and the improvement of including the dress packs in the planning. Finally, Section 7 concludes the paper and discusses future possible research.

2. Dress pack simulation model

The robot dress pack consists of multiple flexible objects such as electric cables and supply hoses tied to each other in a complex way. In order to compute the elastic deformation of the dress pack when subject to a robot motion, we need a proper simulation model. The model must be physically accurate and able to predict large nonlinear deformations. It must also support a variety of boundary conditions to connect the flexible objects to each other as well as to the robot.

2.1. Cosserat rod theory

A *rod* is characterized as a slender object in R^3 , where one dimension (the length) is significantly larger than the other two (the cross section) and that exhibits an elastic behavior. Assuming the cross section is planar and rigid, the configuration q of a flexible segment of length L can be represented by an arc length parameterized framed curve:

$$q: [0, L] \ni s \to \big(\varphi(s), R(s)\big) \in \mathrm{SE}(3). \qquad (1)$$

Here, $R(s) = (d_1, d_2, d_3) \in \mathrm{SO}(3)$ describes the evolution of the cross section orientation along the center curve φ.

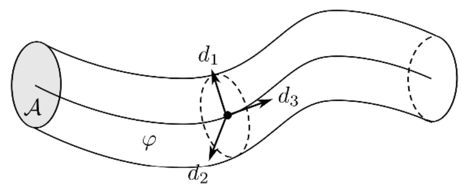

Fig. 1. A rod representation of a cable.

Geometrically exact *Cosserat rod theory* accounts for elastic deformations in the form of both shearing, stretching, bending and torsion. The total potential energy of a configuration q is written

$$W = \int_{s=0}^{L} \{\Gamma(s)^T K_\Gamma \Gamma(s) + \Omega(s)^T K_\Omega \Omega(s) - K_g g^T \varphi(s) + w_C(s)\} ds \,. \qquad (2)$$

Γ is the shearing/stretching strain vector and Ω is the curvature/torsion strain vector in the material coordinate system R. K_Γ and K_Ω are the corresponding effective stiffness matrices. Furthermore, K_g is the length density and w_C is a repelling potential energy density due to conservative contact forces.

According to the Hamiltonian principle, the static mechanical equilibrium of the rod can be found among the stationary points to the total potential energy,

$$\delta W = 0. \qquad (3)$$

2.2. Boundary conditions and clips

The energy formulation of our mechanical system extends naturally to the modelling of multiple flexible segments connected to each other. A wide range of boundary conditions and kinematic clips can therefore be represented by expressing the kinematic relation between connection points in terms of generalized coordinates. In addition to that, link weights and elastic joint springs can easily be modelled by adding corresponding energy terms to the total potential energy of the system.

2.3. Implementation notes

For an efficient implementation of a discrete Cosserat rod model, the potential energy densities are evaluated in terms of geometric finite differences and integrated along the rod with a suitable quadrature rule. Solving Eq. (3) with a quasi-Newton method together with analytically calculated gradient expressions allows for a real-time simulation of the entire dress pack.