Robotics and Computer-Integrated Manufacturing 30 (2014) 34–46

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Intelligent hierarchical robot control for sewing fabrics

Panagiotis N. Koustoumpardis*, Nikos A. Aspragathos

Department of Mechanical & Aeronautics Engineer, University of Patras, Patras, Greece

ARTICLE INFO

Article history:
Received 22 December 2012
Received in revised form
2 August 2013
Accepted 6 August 2013
Available online 11 September 2013

Keywords:
Robotic sewing
Neural networks
Fuzzy logic
Force control
Handling fabrics
Tensile test
Apparel industry

ABSTRACT

In this paper an intelligent hierarchical controller for the robotized sewing of two plies of fabrics is presented. The proposed system is based on the concept: fabric properties estimation – tensional force determination – sewing – adaptation. A new methodology for integrating the tensile test of fabrics into the robotic sewing station using the sewing machine is presented. The output of this test is the estimation of the fabrics extensibility, which is fed to the next level of decision making to determine the appropriate fabric tensional force that should be applied during the sewing process. Computational intelligence methods (fuzzy logic and neural networks) have been used throughout the hierarchical structure of the controller. The present research is focused on the concept of using qualitative properties of the fabrics and the processing of qualitative and quantitative knowledge in different levels of the introduced hierarchical system. The proposed system is flexible, adaptable and robust enough to sew a wide range of unknown double ply of fabrics as it is shown by the test results. It has also the capability of on-line and endless training in order to be able to respond, handle and sew new types of fabrics. Seams that are produced by the robot and a human operator for joining two pieces of fabrics are presented and compared.

1. Introduction

The research on handling fabrics with robots raises new and challenging difficulties that require robotic manipulation methods beyond the current ones. The very low fabric's bending resistance, their large deformations, their unpredictable behavior, their anisotropic nature and their materials' non-linearity and heterogeneity are the main reasons for their handling difficulties. The great variety of fabrics and the difficulties in modeling for real time applications complicate further the automation of their handling. Besides the above difficulties for simple handling tasks, the handling of the fabrics during the robotized sewing problem becomes more complex due to the additional difficulties caused by the periodic movement of the feed dog mechanism, which can be considered as external disturbances. The fabrics should be kept taut when are fed in the sewing machine. The appropriate applied tensional force depends on the fabrics' properties, the composition, their structure as well as the sewing direction. The investigation of the influence of all these factors becomes a very complex problem, while the control of the sewing process is a real challenge.

Several research attempts on robotized sewing of fabrics appeared in the relevant literature. During the '80s and early '90s considerable fundings have been allocated to the research of automating the sewing process. However, the automation in the cloth industry still remains inchoate and most of the production is carried out in countries with very low labor costs. Nowadays, the focus is modified in bringing back the garment production in developed countries, by automating the fabric handling processes. This turn is also encouraged by the growth of computational power, together with the very high speeds in sensors and machine vision processing as well as by the technological improvements of the robots.

Gershon [1] presented the FIGARO project, where an integrated robotic system for sewing has been developed. For the fabric tension control an estimated sewing velocity, using data from the sewing machine shaft encoder, was adjusted so as to derive the robot velocity. In addition, the gains of the proportional-integral robot controller were adjusted by trial and error, which should be modified for a new type of fabric [2]. Gershon [2] clearly justified the need for force feedback control, in order to obtain a fabric's constant tensional force during the sewing process. He also underlined that the conventional control methods are inadequate to handle the fabric tensional force. Makoto Kudo et al. [3] presented a handling system for automated sewing using two cooperative robots, which was their main contribution. A fabric tension control is accomplished between the two acting points of the grippers but not in the sewing direction. They incorporated a

* Corresponding author. Tel.: +30 26 1096 9491.
E-mail addresses: koust@mech.upatras.gr, aspragathos@mech.upatras.gr (P.N. Koustoumpardis).

0736-5845/$ - see front matter
http://dx.doi.org/10.1016/j.rcim.2013.08.001

force control for pressing of the two grippers on the table and visual control for the orientation of the fabric around the needle.

The most critical component, for controlling the sewing process, is the control of the tensional force that should be applied to the fabrics. This is a key factor that affects the quality of the seams. A rich research on robot force control have been published to the robot interaction with rigid environments that presenting very high stiffness, an overview is presented in [4,5]. Less but adequate research appeared for force control of robots in handling semi-rigid objects [6]. However, the field of robot force control for very flexible objects such as fabrics, and particularly when these fabrics are under dynamic motions and external disturbances, has not been investigated so widely. Very few schemes have been presented in the international literature for controlling the force applied by the robot on the fabric, so as to keep the fabric taut during the sewing process or other fabric handling tasks. An adaptive force feedback controller has been used in [7], where the fabric stiffness was the adaptive variable, which was estimated experimentally using a LMS method. The robot held one end of the fabric, while the other one was fixed on a table. The handling task was to straighten out the fabric's initial misalignments-wrinkles and to draw a tension on the fabric. The authors mentioned that non-adaptive force control schemes are unsuitable for fabric handling due to the fabric's stiffness variations caused by the individual taut or slack fibers. This was a static handling task without any disturbances such that caused by the sewing machine.

A model-reference adaptive system has been proposed in [11] and is compared with a PI controller. Fung et.al. [11], used a pair of two-link mechanisms that exerts a prescribed tension to fabrics to facilitate inspection processes. The control of such a static system, where the fabric is not moved, is much easier compared with the case of sewing, where the one end of the fabric is under dynamic and periodic motion.

Another promising approach was presented in [8], where the sewing machine's feed mechanism is redesigned and has been replaced by an especially designed servo controlled manipulator. Their prototype manipulator has been mounted after modifications on the sewing machine. The system was tested under high sewing speeds, while straight line and circular seams for joining multiple fabrics have been realized. It was the first time where the issue of attaching two pieces was addressed.

Recently, an interesting approach is presented in [9], where the sewing cell consists of two lightweight industrial robots and a sewing machine for joining leather parts. The system includes sensors for both force and edge positioning control during the sewing process. A PI controller is used to control the force, which is not applied along the sewing direction. The desired tensional force is defined arbitrarily and its dependence with the type of the sewed leathers is not mentioned. The same research team presented [10] also an interesting embryonic preliminary investigation about the feasibility of using two robotic arms for sewing two different hide parts with different shapes. The strategies, which presented in both [9,10], include measuring and control of the sewing machine's speed.

Computational intelligence methods have been used previously for robot force control in several handling tasks of rigid and semi-rigid objects [12,13]. But, these methods have not been used in the robotized sewing problem for controlling the forces that applied on the fabrics. Despite that the force control is easier, when the robot is in contact with a compliant environment, the difficulties are obsessive due to the interaction with the sewing machine. In our previous work [14], the efficiency of a neural network's force controller for the feeding of a single piece of fabric to the sewing machine has been studied. This was a theoretical approach and a feasibility study of the robotized sewing problem was presented. This system was tested by simulation where the tensile behavior of the fabric was modeled and the sewing machine's speed was assumed to have an ideal constant value. In [15] preliminary experiments of robotized sewing have been presented, where only single pieces of fabrics have been sewed. It was the first time, where a single neural network has been used for controlling the force and stitching only one piece of fabric. Recently, the control of the tensional force has been based on a fuzzy model reference adaptive controller [16] with promising preliminarily results.

This paper presents an integrated robotized sewing system, which is based on a hierarchical robot control, in order to join two pieces of fabrics with an industrial sewing machine, while controlling the force applied by the robotic manipulator. The necessity of establishing the idea of a “common language”, for expressing and handling the qualitative fabric properties with linguistic variables, through the cloth making industry chain is explained. A new methodology for integrating the tensile test of fabrics into the sewing process using the sewing machine is presented, where two pieces of fabrics are subjected in the tensile test. This preprocessing for the estimation of the fabric characteristics is integrated in the robotized sewing system towards greater autonomy and flexibility. The system is independent and uncoupled from the sewing machine since it does not require any measurement or estimation of the sewing speed. The required properties of the fabrics for achieving high quality sewing are processed through a hierarchical structure using computational intelligence methods. Our previous work [23] on estimating the extensibility of a single piece of fabric is adapted and extended to two pieces of fabrics using the new robotized tensile test. An improved feedforward neural network controller is used in order to regulate the tensional force applied to the joined pieces of fabrics during the sewing process. A wide range of knitted and woven double ply fabrics with varying compositions are sewn. Each type of the fabrics is sewn by the robot as well as by a human operator. The produced by the human and the robot seams are compared and their quality is discussed.

The structure of the paper is organized as follows. The complexity of the sewing problem and the difficulties appeared in its automation are discussed in the next section. The hierarchical control scheme and its components are presented in Section 3. The experimental setup and results for joining two pieces of fabrics and the produced, by the robot and the human, seams are presented in the last Section 4.

2. Description, needs and specifications of the “robotized sewing problem”

The automation in the apparel industry and particularly in the sewing of fabrics, cloths etc. is more necessary nowadays than ever. This industry sector is one of the last industry towers to be conquered by the robotic automation. The efforts for repatriating the clothing industry back in the developed countries has been started [17] and the advanced intelligent robotic systems are the key factor for this.

A robotized approach that will have the chance to succeed in this high economical impact industry should be able to deal with the very wide variety of fabrics having very different properties. These robotic systems should be as autonomous as possible with the lowest human intervention and should be capable to handle qualitative and quantitative knowledge. The control structure should have the influence to cope with the high complexity posed by the nature of the fabrics and sewing process. Such a system should be adaptable and flexible in order to cooperate with different types of sewing machines and different adjustment of the sewing machine parameters.