Computer-Aided Engineering and Mechatronics in the Design of Apparel Equipment

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ANNUAL REPORT: August 1996- Present.

ABSTRACT:

This research project combines computer-aided-engineering methods with practical control strategies to develop precise fabric part handling capabilities. The primary goal is to develop mechatronic design concepts for assembly processes such as: folding, joining, placing, and locating that take into account variability in fabric material properties such as weight and stiffness. Three-dimensional modeling of fabric drape and manipulation using the finite element method has been simplified for the design of fabric handling control systems. The machine implementation aspect of this years research focuses on real-time position control for draping fabric that is sliding on a high friction surface. Although fabrics are usually positioned on smooth surfaces with fixed fabric guides to simplify automated handling, a high friction work surface holds the fabric in place after positioning, allowing accurate assembly of multiple fabric parts without specialized jigs or fixtures. A neural adaptive controller with feed-forward friction compensation provides asymptotic tracking for a spring mass model with friction. A test stand and an optical sensor are designed to facilitate real time position measurement and control. The neural adaptive controller demonstrates good position tracking and robustness to fabric property variations relative to open loop or PID control.

I. PROJECT GOALS AND RELEVANCE TO NTC GOALS

The key question and challenge for this research project is: Can computer-aided-engineering techniques commonly used in the automotive and aerospace industries be applied to the design and development of fabric handling equipment? And, can the machinery be designed to accommodate multiple part configurations (shape, thickness, etc.) and material properties (weight, stiffness, etc.)? The major objective of this research project is then to combine computer-aided-engineering methods with practical control strategies to develop precise fabric handling capabilities. The primary goal is to develop mechatronic design concepts for assembly processes such as: folding, joining, placing, and locating that take into account variability in fabric material properties such as weight and stiffness. Advanced three-dimensional modeling of fabric drape and manipulation using the finite element method will be simplified for the design of fabric handling control systems. Controls that stabilize the fabric motion and allow accurate handling with minimum wrinkling will be investigated. Proof of concept demonstrations have been constructed to show techniques for systematically adjusting for material property variation. Other potential applications for this technology in future years would include 3D fabric processes such as shape pressing and sewing.

Computer-aided-engineering is prevalent in many high technology industries in the US, including automotive and aerospace. Computer simulation of manufacturing processes during the equipment design phase is an accepted procedure. This same approach must be implemented in the design of fabric handling equipment. Machinery must be engineered in advance to accommodate multiple part configurations and material properties. Competitive advantage from Demand Activated Manufacturing will require this level of knowledge.

II. TECHNICAL APPROACH AND PROGRESS

Flexible automation allows apparel manufacturers to respond quickly to rapidly changing market conditions while minimizing skilled labor. Successful automation in the apparel industry has primarily been limited to fixed automation using special purpose, mass production machines. Flexible automation using general purpose machines is difficult because the limp nature of the fabric complicates actuation and sensing, thus adding cost and complexity. A wide variety of materials need to be handled with diverse bending stiffness, weights, and frictional characteristics. Additionally, these characteristics vary from part to part and with temperature and humidity. Dependable flexible automation requires feedback to adapt to these variations.

A number of researchers focused on automating entire apparel manufacturing lines. The Charles Stark Draper Laboratory and Textile/Clothing Technology Corporation [1.] applied large scale automation to the men's clothing industry. MITI [2.] implemented similar apparel automation systems. Taylor and Taylor [3.] developed an automated line for the assembly of men's underwear. Other researchers concentrated on fabric handling. Gunner [4.] investigated the laying of fabric strips on moving conveyor belts. Brown et. al. [5.] used Konopasek's [6.] equations to derive trajectories for fabric standing. Eischen and Kim [7.] used a nonlinear technique to solve for fabric standing up, laying down, and folding trajectories.

During past years (see [8.] and [9.]) we focused on iterative position control for folding on a friction-less (slippery) work surface, a fundamental fabric handling operation. A fast, memorized folding trajectory was implemented using an industrial robot. A vision system measured the fabric position error after each fold. If the error was too large, the trajectory was modified on-line and the fabric was then refolded. This process repeats until small errors are achieved. This past year, with NTC funding, we have focused on real-time position control for draping fabrics sliding on high friction (rough) surfaces.

Neural Adaptive Control For Positioning Fabric On A Frictional Surface

This years research focuses on real-time position control for draping fabric sliding on a high friction surface. Although fabrics are usually positioned on smooth surfaces with fixed fabric guides to simplify automated handling, a high friction work surface holds the fabric in place after positioning, allowing accurate assembly of multiple fabric parts without specialized jigs or fixtures. A neural adaptive controller with feed-forward friction compensation provides asymptotic tracking for a spring mass model with friction. A test stand and an optical sensor were designed to facilitate real time position measurement and control. A new neural adaptive controller demonstrates good position tracking and robustness to fabric property variations relative to open loop or PID control.

Figure 1 shows the experiment designed for fabric positioning control. A linear slide is driven on guiding rails by a Baldor model 3300 brushed DC motor. A toothed endless belt converts the rotary motor shaft movement to linear slide motion. A Hohner 1000-count rotary encoder measures the DC motor angle. Four fabrics are used with wide ranging weight and stiffness (see [8.] for fabric properties). One end of the fabric is looped around a circular rod that is fixed to the linear slide. The fabric moves on a Plexiglas surface bonded with 400 grit sandpaper. An optical vision sensor measures the fabric edge position with a 0.1 mm resolution and response time of 1 ms.

PID control is implemented with Fabric 3 and compared with an open loop experiment. The open loop experiment (see Figure 2) shows poor positioning accuracy with a final positioning error of 50 mm. In the figure $y(t)$ (output) is the fabric edge position while $u(t)$ is the slide position (input). The PID gains are fine tuned to obtain a position accuracy of a millimeter for Fabric 3. From the fabric tracking performance for a multiple step trajectory (see Figure 3) it is observed that the PID controller shows satisfactory performance with a final position error of 0.8 mm. During the second step, however, the slide moves backward, trying to push the fabric. Due to the large friction, however, the fabric edge does not move. This can cause the slide to drift. The final positioning error of 0.4 mm is very good, however. Table 1 shows that the performance of the PID controller significantly degrades when the gains tuned for one fabric are used on other fabrics. In the worst case (Fabric 1), the final positioning error increases by a factor of four. This poor robustness, coupled with the tendency for backwards slide motion, motivate the neural adaptive controller.

Figure 4 shows the block diagram of the neural adaptive controller. The neural adaptive controller is implemented with Fabric 3 and tuned for best performance. For the multiple step trajectory, the controller performance (see Figure 5) is a good trade-off between fabric position tracking and control smoothness. The motion becomes smoother as the neural network is sufficiently trained. The slide does not move backward after adaptation. The fabric positioning is consistent for each consecutive step after the first step when the network estimate converges to a constant value. The neural controller also performs consistently well with other fabrics using the gains tuned for

Fabric 3 (see Table 1). The final errors for the three other fabrics are within the 1 mm specification. Thus the robustness of the neural controller allows accurate positioning for a wide range of fabrics without operator adjustment.

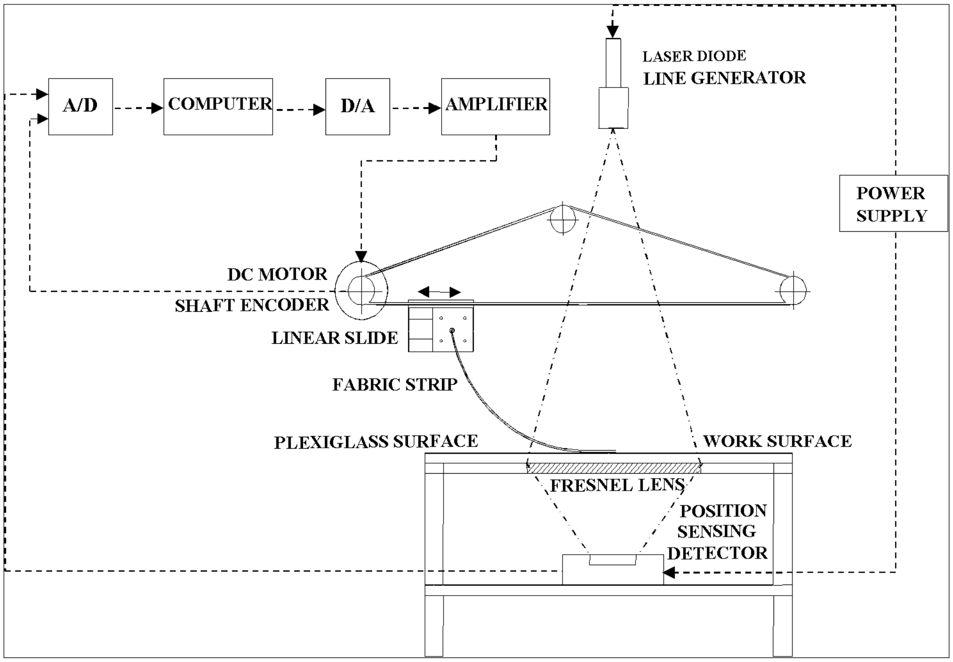

Figure 1- Schematic diagram of the fabric positioning control experiment

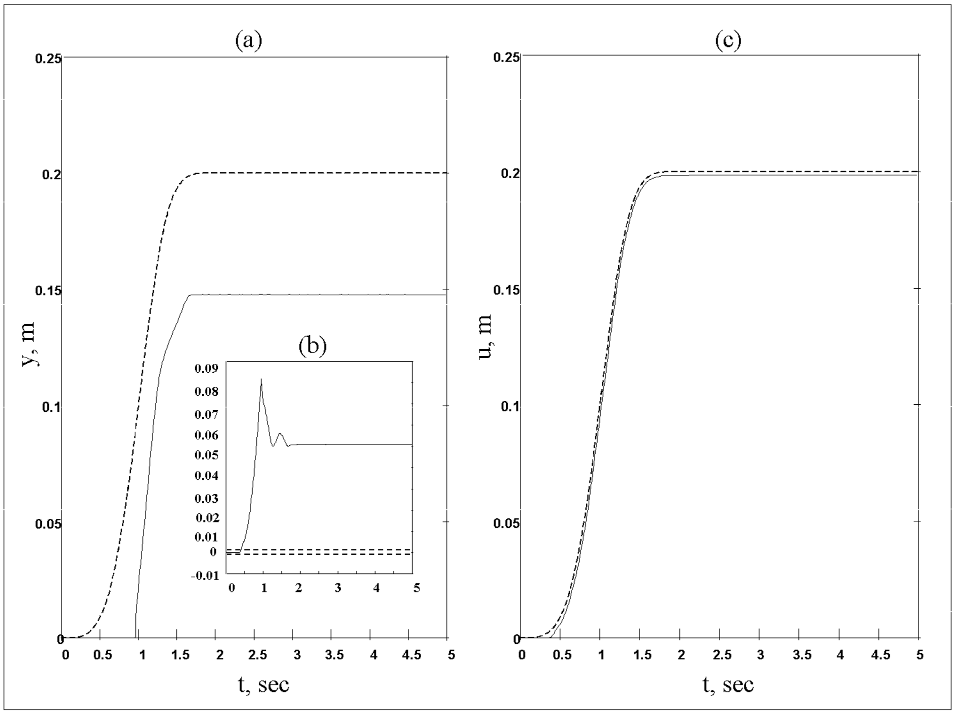

Figure 2- Open loop fabric positioning experiment: (a) actual (solid) and dashed (desired) fabric position; (b) fabric position error, dashed lines represent +/- 1 mm desired specification; (c) actual (solid) and dashed (desired) linear slide position.

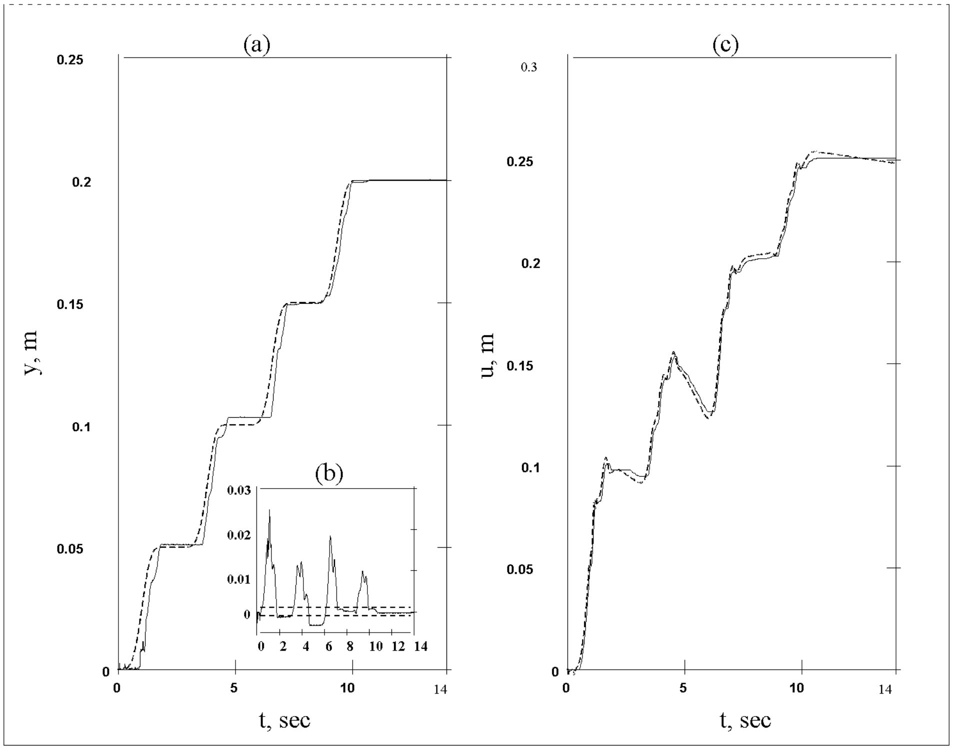

Figure 3- Multiple step PID control experiment: (a) actual (solid) and desired (dashed) fabric position. (b) fabric position error, dashed lines represent +/- 1 mm desired specification. (c) actual (solid) and desired (dashed) linear slide position.

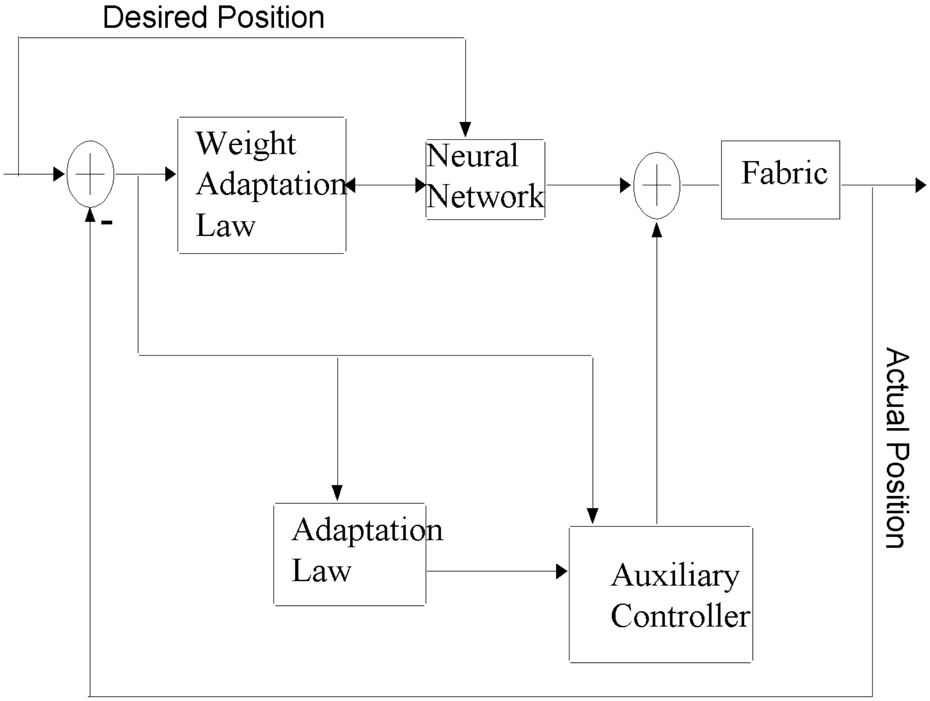

Figure 4- Block Diagram of the Neural Adaptive Controller

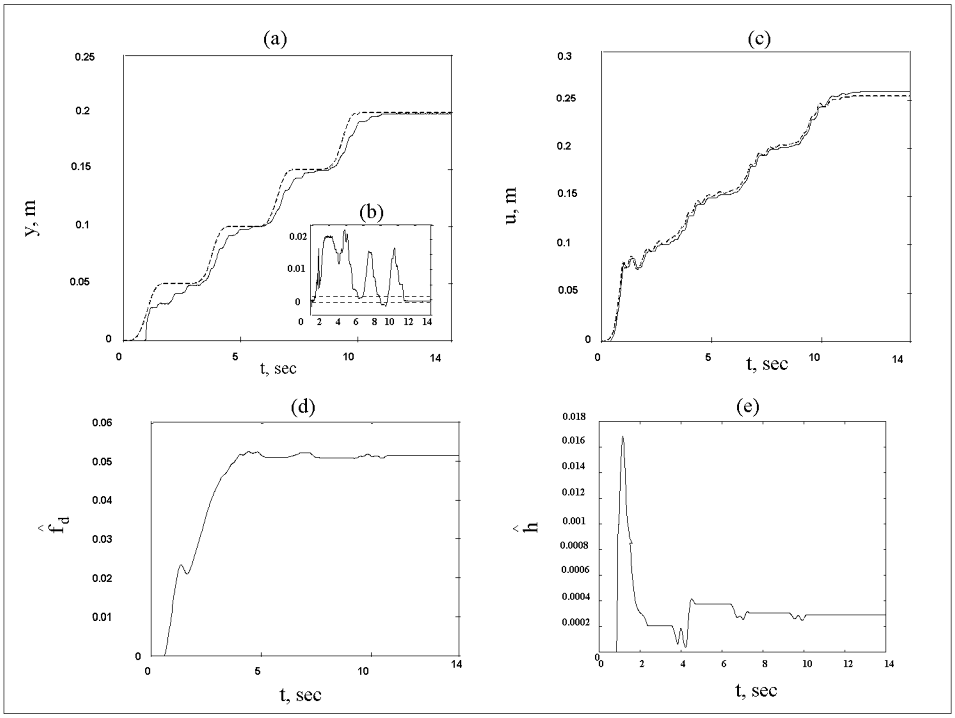

Figure 5- Multiple step neural adaptive control experiment: (a) actual (solid) and desired (dashed) fabric position; (b) fabric position error, dashed lines represent +/- 1 mm desired specification; (c) actual (solid) and desired (dashed) linear slide position; (d) friction estimate; (e) adaptation estimate.

	PID	Neural
Fabric Type	Final Error (mm)	Final Error (mm)
1	1.6	0.7
2	1.2	0.9
3	0.4	0.8
4	0.9	0.8

Table 1- Positioning performance for a variety of fabrics (Controllers tuned for Fabric 3)

Computer Simulation

A computer simulation tool has been developed that allows modeling of various fabric manipulation processes that occur during manufacturing. Fabric parts are modeled as very flexible elastic beams that can accommodate stretching and bending in a single plane. The governing equilibrium equations are solved using the finite element method. The nonlinear moment curvature response is measured directly with the Kawabata Test System, or with a simpler drape test. Realistic manipulation processes involve interaction of fabric parts with other objects such as: work surfaces, robot manipulators, other fabrics. Therefore, the ability to model contact has been implemented. A key aspect of this research was development of a capability to determine optimum ways to manipulate fabric parts while minimizing sliding of the fabric or forces generated in the fabric. This feature allows intelligent selection of initial manipulation paths for the control system just described. Details of the finite element approach are given in [10.] and [11.]. A Visiting Scholar from Italy with expertise in 3D fabric drape (clothing on mannequins) and computer graphics has recently joined the NCSU team.

Conclusions

Three-dimensional modeling of fabric drape and manipulation using the finite element method has been simplified for the design of fabric handling control systems. The machine implementation aspect of this years research focuses on real-time position control for draping fabric that is sliding on a high friction surface. A neural adaptive controller with feed-forward friction compensation provides asymptotic tracking for a spring mass model with friction. A test stand and an optical sensor are designed to facilitate real time position measurement and control. The neural adaptive controller demonstrates good position tracking and robustness to fabric property variations relative to open loop or PID control.

IV. INDUSTRY COLLABORATION

Leonard Brewington at Milliken arranged for us to visit the American Bag Corporation airbag manufacturing plant during the Fall of 1996. We have characterized airbag materials at NCSU in order to simulate manufacturing processes on the computer. We have also built a CAD database with detail dimensions. Clemson is currently investigating mechatronic issues such as gripper technology and handling strategies for arbitrary shaped fabric parts such as airbag components. Future automation of airbag assembly could potentially benefit from our research findings. We are also initiating research with Ford Motor Company in the area of computer simulation of manufacturing processes related to automotive electronics. We are also working with TC^2 in the area of experimental validation of fabric drape on 3D objects (mannequins). It is our intention to tailor our experimental investigation towards fabric handling problems that are relevant to industry problems.

V. PUBLICATIONS

1. “Iterative Techniques for Fabric Position Control During Folding,” submitted to International Journal of Clothing Science and Technology, June 1996.
2. “Finite-Element Modeling and Control of Flexible Fabric Parts,” IEEE Computer Graphics and Applications, Special Issue on Computer Graphics in Textiles and Apparel, Volume 16, Number 5, pp. 71-80, (Invited Paper)
3. “Optimum Manipulation Strategies for Limp Fabric Materials,” with W. Clifton, Proceedings of the Fifth Pan American Congress of Applied Mechanics Conference, San Juan, Puerto Rico, Jan. 1997.

4. "Optimum Fabric Trajectories for Edge Position and Control," Clifton, W., MS Thesis, North Carolina State University, 1996.
5. "Iterative Techniques for Control of Fabric Manipulations," Mast, S., MS Thesis, Clemson University, 1997.
6. "Neural Adaptive Position Control of Fabric on a Frictional Surface," Shenoy, S., MS Thesis, Clemson University, 1997.

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10. "Finite-Element Modeling and Control of Flexible Fabric Parts," IEEE Computer Graphics and Applications, Special Issue on Computer Graphics in Textiles and Apparel, Volume 16, Number 5, pp. 71-80.
11. "Optimum Fabric Trajectories for Edge Position and Control," Clifton, W., MS Thesis, North Carolina State University, 1996.