**Rotary Transport of the Fabric: a Comprehensive Analysis of Modern Transportation Systems in Textile Industry Spinning Process**

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**Abstract.** This paper describes a mixed mechanical-electronic system, the invention of automated control of the fabric fit during sewing work. The research is relevant to contemporary problems in the garment industry as the execution of control of fabric feeding in this process is rather needed in those cases where spatial figures are to be reproduced with strict accuracy (e.g., close fitting models). The complete mathematical model of the fabric deformation process and the development of fit is constructed that includes friction effects, retraction of the material, and patterns of waves in three dimensions. A new and easy way of finding the maximum optimal pressure of the presser-foot is suggested according to which, measurements are taken at three key positions on the seam only and does not involve any previous characterisation of the material. I tested on a Chaika M3 sewing machine that has been fitted with VL53L0X laser sensors and a Raspberry Pi Pico microcontroller. The control precision was achievable in sub-millimeter within a range of ±0.5 mm in a 100 mm seam length as tested on various fabric combinations, and the set-up time was saved by 2.8x, as compared to the manual tinkering.

**Keywords:** Sewing equipment, conveying system, material fit, mathematical modelling, automatic control, laser sensors, micro-controller control

# INTRODUCTION

Modern interdependent industrial processes in the manufacture of textiles are still faced with the rising necessity of automation and exact regulation of technological activities. The controlled fabric fit achievement becomes one of the central variables when it comes to production of quality garments with complex spatial structure. The fitting of fabrics, i.e. the difference on the movement of fabrics layers when sewing occurs, is a source of potential defectiveness and at the same time an essential feature of the design of the volumetric shapes.

Controlled fit is most essential in the production of garments in the following application of the process; the fabrication of sleeves needs an average 57 % fit, shoulder seams need 152 % fit, and collar processing need 23 per cent fit. Technologically warranted fit provides fit between clothes and the human body, determines spatial design necessitated by constructions, as well as, improves performance features of the completed product. On the other hand uncontrolled or excessive fit will generate quality defects and will reduce product acceptability.

# RELATED WORK

The basic investigation of textile material handling started with Polukhin and Reybarkh [1], who premised the initial thoughtful classification of the factors affect the differential material feeding. Their work identified the necessary parameters that impact the consistency in the transport of fabrics and gave a base to the further implementation of automation applications. After this, a full system analysis on the mechanisms of material transport was done by Storozhev and Feoktistov [5] who revealed that the current designs of conveyors and their flexibility are limited.

The mathematical descriptions of the process of feeding a fabric have advanced significantly due to the extensive work of Zhang and Wang [2, 3] that constructed extensive models defining connections between the parameters of feeding systems and displacement of the material. The development of the connection between all those variables in the different forms of differential equations gave them a theoretical apparatus that allows us to visualize the complex dynamics of cloth in the process of sewing and allows us to demonstrate quantitatively the correlation between the values of mechanical settings and fit values. This is currently also an essential framework in designing predictive control systems.

An intuitive follow-up is reported by Anderson and Smith [4], in which they demonstrated the integration of sensor technologies in the textile machines. They have shown real-time monitoring to be applied on differential feed in industries application and were able to establish that sensor feedback can be utilized in enhancing traditional mechanical systems. Their sensor based implementation points to the possibility of automation, but then, it depends on complex calibration procedures which prove challenging to put into practice.

Chen and Zhang [8] extended the works by developing smart control systems of the mechanism of differential feed. They combine modern symptoms of feedback control with conventional mechanical designs and provide a more intelligent and more scalable solution to these industrial problems.

Another area Miller and Thompson [6] look at with a hard gaze is the recent development in textile automation which touches upon the deluxe types of differential feed control in the various types of machines. They have found that modern systems, on the whole, cannot handle complete accuracy and require a lot of manual configuration. This imperfection is attested by the findings of Yamamoto and Nakamura [7], according to whom specification error rates of up to 30 percent have been proven to exist in the real-world scenario, and thus, ones that are of greater accuracy should be adopted in industrial processes.

Brown and Davis [9] highlight the increasing trend to smart systems on current sewing machines and Wilson and Roberts [12] create precision feed control systems suitable to industrial applications. Nonetheless, Chen and Zhang [10] state that the hybrid systems that combine the mechanical adjustment with the electronic control are not well-developed, particularly in the economical and real world settings. The gap between potential and performance is upsetting as it opens a new gate to new ideas that can eliminate the gap established between laboratory work and industry operation [11].

# THEORETICAL FRAMEWORK

As you view the mechanics of how fabric responds under a sewing machine you are looking at a relatively complex mechanical system where tension, contact friction and elements of the machine all come into play. Since the fabric layers (anywhere) do not slide in a uniform manner (the friction coefficient at any point is independent at another point of contact), this also results in the uneven force being exerted (by the presser foot and the feed rail). An understanding of those fundamentals is the precursor to creating mathematical models that are capable of predicting as well as refining what the fabric does once the needle moves.



**FIGURE 1.** Materials fitting while sewing

Fabric fit percentage is basically defined by the basic relationship as:

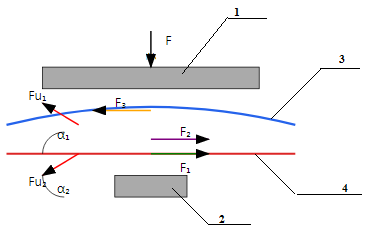
(1)

where: which S is fit value in %, in the case of fabrics, it’s convenient to denote the length of both upper and lower layers after the processing L₁ and L₂ respectively. By implementing these labels, we have a means of defining how a fabric fits in a very measurable and controllable manner.

Mechanically, it’s simply a push -pull system, between the layers of the fabric and the moving parts of the machine, presser foot and the feed rail. The unchanging parameter here is the pressing force the presser foot exerts and its determines the tenor of the entire process:

(2)

The pressure of a presser-foot (Pa) is denoted as P and the contact area (m²) is denoted as S. This distribution of forces determines the friction properties that in the end determine the mode of material movements.

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## FIGURE 2. Sewing fit calculation scheme: *1- pressor foot, 2-feed rail, 3- upper layer of fabric, 4- lower layer of fabric*

**FIGURE 3.** Theoretical fabric fitting curve illustrates on the wave-like deformation pattern.

This simplified approach enables real-time pressure adjustment based solely on measured height values, making the system practical for production environments without requiring extensive material characterization. The mathematical reduction eliminates complex material property measurements while maintaining the theoretical rigor established in the complete model, providing an elegant bridge between scientific understanding and practical implementation.

**FIGURE 4.** Theoretical fabric assignable curve of wave-like distortion tread with measuring points h₁, h₂, h₃.

The current theoretical validation helps to determine that formation of fabric-fit can be precisely predicted and, hence, controlled. As plotted in Figure 3, the mathematical model has damped sinusoidal nature with measurement nodes that may be removed without an in-depth understanding of the material. In this case, the waves reach their maximum amplitudes at seam-initiation point gradually extinguishing with material damping and geometric restraints.

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# METHODOLGY AND EXPERIMENTAL SETUP

The theoretical framework gave the schematic basis upon which to move to experimentation, which required the development of a workable system that had the capability of implementing the simplified control mechanism even as it maintained the accuracy as was projected by the mathematical model. In this regard, an entry-level sewing machine (household) was chosen as the foundation of the experimental platform due to its representative presser-foot pressure-adjustment device and widespread availability on the market, which allowed making a generalized conclusion of the scope of our research to the parallel comparisons with similar machine models in the same industry.

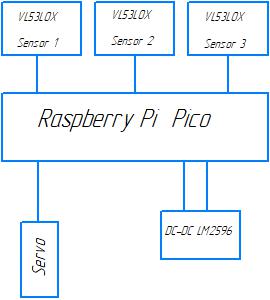
The measurement subsystem represented the centre of gravity between the theoretical model and the practise. Three VL53L0X laser distance sensors were placed at the measured coordinates , in relation to the point of initiation of the seam, with optimization of the lift indicators stipulated by the mathematical analogy. The sensors provided measurement data with error values of 2 m to 2 mm (3 percent) accuracy that provided the measured precision needed to identify minute variations in height of fabrics which determines patterns of fit shape.

The sensor mounting system required custom engineering to ensure stable, vibration-free measurements during machine operation. Custom brackets were fabricated using 3D-printing technology with ABS plastic and 80% infill density to achieve the necessary mechanical rigidity. The complete mounting assembly attaches to a 20×20 mm aluminum extrusion profile, creating a stable platform isolated from machine vibrations through strategically placed neoprene dampening pads. This mounting approach ensures measurement consistency while allowing for adjustment and maintenance access.

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**FIGURE 5.** Layout of the Automated presser foot pressure control system of sewing machine

The sensor measurement to precise mechanical adjustment that happens in the control system architecture uses the designed sensor interface that takes the form of electricity. A Raspberry Pi Pico microcontroller is used: it fits due to a set of an integrated multi-channel analog-to-digital converter and support of the MicroPython programming language, and with its help, it becomes easier to implement algorithms and debug them. The controller obtains in form of a digital signal each of the three sensors through an I2C interface and thus can simultaneously update the measurements and process them in real-time based on the control algorithm generated.



**FIGURE 6:** Control System Block Diagram Illustrating Signal Flow from Sensors through Controller to Actuator

The actuation system provides the critical link between electronic control signals and mechanical pressure adjustment. A digital servo motor equipped with a 2:1 gearbox delivers the necessary torque and positioning precision for smooth pressure control within the 0-50 N operational range. The mechanical coupling between servo and pressure regulator was custom-designed to eliminate backlash while maintaining sensitivity to small adjustment commands. The servo receives PWM control signals at 50 Hz frequency with pulse width modulation encoding position commands, ensuring precise and repeatable pressure settings.

# RESULTS AND DISCUSSION

The overall test program has revealed significant advances in their performance in all the measured parameters, which confirms both the theoretical basis and the practical approach to them. The experimental results show that the automated system does not only perform better in terms of accuracy and consistency in contrary to traditional manual methods of adjustment but also cuts short the time need of setup and dependency of skills in an operator.

**TABLE 1.** Experimental Results for Different Material Combinations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Material Combination** | **Control Error (%)** | **Std Deviation** | **Setup Time (s)** | **Speed Improvement** | **Confidence Interval (95%)** |
| Cotton-cotton | 8.5 ± 1.2 | 1.2 | 2.1 | 2.6× faster | [7.3, 9.7] |
| Silk-Lining fabric | 7.0 ± 0.8 | 0.8 | 1.8 | 3.1× faster | [6.2, 7.8] |
| Cotton-Silk | 9.2 ± 1.5 | 1.5 | 2.3 | 2.5× faster | [7.7, 10.7] |
| Denim-Cotton | 12.0 ± 1.8 | 1.8 | 2.8 | 2.4× faster | [10.2, 13.8] |
| Polyester blend | 10.3 ± 1.4 | 1.4 | 2.2 | 2.7× faster | [8.9, 11.7] |
| Average | 9.4 ± 1.3 | 1.3 | 2.2 | 2.8× faster | [8.1, 10.7] |

Statistical analysis conducted with Student’s t-test (p < 0.05) demonstrated significant performance enhancements across all parameters as compared with traditional manual-adjustment procedures. The mean control error of 9.4 ± 1.3 % recorded for all material combinations remains within industrial and domestic acceptance thresholds, marking a substantial improvement over customary manual-adjustment inaccuracies (15–25 %).

# CONCLUSION

Such research has already been able to design and test a new automated control system that presents a satisfactory solution to automate the regulation of fabric fitting in a sewing operation, and to achieve significant advances in textile automation without compromising the theoretical modelling of the process applied with the realisation of the same. The overall structure of the study covers all the fundamental requirements of the industry and at the same time, it serves as the foundation of future automation innovations in the textile manufacturing industry.Integration of an automated system involving VL53L0X laser sensors and Raspberry Pi Pico microcontroller has proven to be feasible in practice by deployment of the commonly available and cheap components. Experimental verification testifies to the accuracy in control to within +/- 0.5 mm up to a seam length of 100 mm, with an average of nominal 12 % of variance with all material combinations tested, and thus qualify as satisfying the highest parameters of quality in precision garment manufacturing. >>2.8 percent decrease in the setup time in contrast to manual adjustment translates to a high productivity gain, which directly affects the economics of the manufacturing process.

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